PORTO RICO AGRICULTURAL EXPERIMENT STATION,
D. W. MAY, Agronomist in Charge,
Mayaguez, P. R.

BULLETIN No. 25.

Under the supervision of the STATES RELATIONS SERVICE,
Office of Experiment Stations, U. S. Department of Agriculture.

THE BAT GUANOS OF PORTO RICO AND THEIR FERTILIZING VALUE.

BY

P. L. GILE, Chemist,

and

J. O. CARRERO, Assistant Chemist.

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[Under the supervision of A. C. TRUE, Director of the States Relations Service, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL.

PORTO RICO AGRICULTURAL EXPERIMENT STATION,
Mayaguez, P. R., February 13, 1917.

SIR: In the present diligent search for all possible sources of fertilizing material, natural deposits, especially of phosphates, are of special interest. One of the natural resources of Porto Rico is the guano deposited by bats in the many caves of the limestone sections. These guanos have been used as fertilizers for years, but without a clear conception of their value or the manner in which they can be employed best.

This manuscript gives the results of extended studies on the composition and fertilizing value of these deposits and should prove of considerable value as a guide to Porto Rican planters. I recommend that it be published as Bulletin No. 25 of this station.

Respectfully,

D. W. MAY,
Agronomist in Charge.

Dr. A. C. TRUE,
Director States Relations Service,
U. S. Department of Agriculture, Washington, D. C.

Recommended for publication.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

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[1] Appointed Mar. 1, 1918, to succeed R. H. Van Zwaluwenburg, transferred to United States Department of Agriculture, Bureau of Entomology.

THE BAT GUANOS OF PORTO RICO AND THEIR FERTILIZING VALUE.

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INTRODUCTION.

Deposits of bat guano have been reported from the southern United States, most islands of the West Indies,[1] Brazil, Uruguay,[2] the Philippines, Marianas,[3] the Federated Malay States,[4] India,[5] Transvaal,[6] Egypt, Italy, Sardinia, southern France, the shores of the Mediterranean, and Austria-Hungary.[7] They evidently occur wherever conditions are adapted to the existence of bats in large numbers and suitable congregating places are afforded.[8]

As the composition of guanos depends more on the leaching, etc., to which they have been exposed than on the composition of the original substance, many of these deposits are similar to certain phosphatic guanos formed by sea birds. The individual deposits originating from sea birds, however, are much the larger, for although both birds and bats congregate in immense numbers, the birds consume much more food.

Scattered through various publications many analyses of bat guanos can be found, although apparently no thorough study of the

[1] Cousins, H. H., Local deposits of bat guano, Bul. Dept. Agr. [Jamaica], 1 (1903), No. 6-7, pp. 144-146. Ageton, C. N., The origin, composition, and fertilizer value of the bat guanos of Cuba and the Isle of Pines, Modern Cuba, 3 (1915), No. 2, pp. 48-59. Miller, C. F., On the composition and value of bat guano, Jour. Indus. and Engin. Chem., 6 (1914), No. 8, pp. 664, 665.

[2] Schroeder, J., Composition of bat guano from Uruguay. Rev. Assoc. Rural Uruguay, 44 (1915), No. 9, pp. 529-531.

[3] Kanamori, S., On bat guano from Marianne Islands. Bul. Col. Agr., Tokyo Imp. Univ., 7 (1907), No. 3, pp. 461-464.

[4] Dunstan, W. R., Report on four samples of bat guano from the Federated Malay States. Agr. Bul. Straits and Fed. Malay States, 4 (1905), No. 10, pp. 394-399.

[5] Thompstone, E., Bats' guano in Burma. Agr. Jour. India, 4 (1909), No. 4, pp. 379-381.

[6] Ingle, H., The Wonderfontein caves. Transvaal Agr. Jour., 3 (1905), No. 10, pp. 217-221.

[7] Fritsch, J., The Manufacture of Chemical Manures, translated by D. Grant, London, 1911, p. 287. Rümpler, A., Die käuflichen Düngestoffe, revised and enlarged by R. Woy, Berlin, 1911, 5 ed., p. 127.

[8] Campbell, C. A. R., The eradication of mosquitoes by the cultivation of bats. Internat. Inst. Agr. [Rome], Mo. Bul. Agr. Intel. and Plant Diseases, 4 (1913), No. 8, pp. 1175-1181, pls. 2. In this article, the author gives interesting data on the amount of excrement voided per bat and results from an experimental bat roost which, he claims, show that it is commercially profitable to build roosts for the manure yielded.

deposits has been made in any one place.[1] There is especially a lack of information concerning the availability of the nitrogen and phosphoric acid present in bat guanos and the availability of phosphoric acid in leached bird guanos. The solubility of the phosphoric acid in neutral ammonium citrate can not be considered a reliable measure of the availability until supported by vegetation tests, as this chemical method is largely empirical and not adapted to all classes of phosphatic fertilizers.

In Porto Rico bat guanos have been used as fertilizers for many years to a limited extent, but without much idea of their real value. The contents of some caves have been examined at various times by different individuals, evidently with a view to exploiting them, but the small size of the deposits and the variation of the material probably prevented this.

For an intelligent utilization of these deposits it is obviously necessary to know the location and chemical analysis of the different kinds of material in each deposit and to have some general knowledge of the availability of the fertilizing constituents. In the following pages are given the locations of the different kinds of material in each cave, descriptions of the samples, chemical analyses, and the results of vegetation tests on the availability of the phosphoric acid and nitrogen. On account of the great variation in the material, it was necessary to make a detailed survey in order to give the work local value. The availability tests have a certain value for bat guanos and leached bird guanos in general.

DESCRIPTION OF GUANO DEPOSITS.

EXTENT OF DEPOSITS

The hundred or more deposits examined in Porto Rico were all found in limestone caves (see Appendix). The size of the individual deposits varied according to the number of bats, the size of the cave, and the protective conditions afforded. Most deposits were small, the largest being that of "El Oscuro" at Morovis, conservatively estimated as consisting of about 3,000 tons. This agrees well with the reports of similar deposits in other countries, which apparently are very rarely of great size. The deposit near Cracow of 4,000 tons is spoken of as the largest European deposit. Ageton,[2] however, estimates a deposit in Cuba as consisting of some 40,000 tons of high-grade material. This is the largest deposit yet reported.

[1] Analyses of one or more samples are given in the articles cited on page 3. R. F. Hare, in New Mexico Sta. Rpt., 1904, pp. 36–40, gives analyses of some 150 samples of bat guanos. Analyses of a few samples are to be found in Texas Sta. Buls. 35 (1895), 51 (1899), and 85 (1906), and in the fertilizer bulletins of some other State agricultural experiment stations.

[2] Ageton, C. N. Loc. cit.

In most Porto Rican caves the guano forms a layer about 3 feet deep over the floor of the cave, although some caverns contain 6 to 10 or more feet of guano, especially where there are pocketlike depressions in the floor of the cave. Most of this material is ready for use as it exists. In some cases, however, it contains 10 to 30 or 40 per cent of stony concretions that should be screened out before it is transported any distance. The fresh bat manure requires no screening.

KINDS OF MATERIAL AND MANNER OF FORMATION.

Although there are no sharp distinctions between the different kinds of bat guano, they may be roughly divided into three classes—bat manure, decomposed guano, and phosphatic guano. It should be borne in mind that this is not a rigid classification, as there are all conceivable grades of guanos. The classification is probably most useful in considering the formation of the guanos, which will be taken up under the description of the three classes of material.

Bat manure.—Bat manure is, of course, the fresh material voided by the bat. Its nature depends chiefly on whether excreted by frugivorous or insectivorous bats. The solid material in the manure of frugivorous bats consists largely of fruit and berry seeds. Samples Nos. 376 (Table III) and 828 (Table IV) represent this material.

Nearly all Porto Rican deposits come from insectivorous bats, the solid matter in the manure consisting chiefly of undigested parts of insects, as wings, legs, and other chitinous parts. The fresh bat manure is easily distinguished from the older guano by its peculiar physical nature. It consists of small excremental lumps, is dark brown in color, and when dry glistens somewhat, owing to the insects' wings. It has a peculiarly low volume weight, only about one-fourth to one-fifth that of other kinds of guano when dry.

Chemically the fresh manure contains a large amount of chitin, the chief constituent of insects' skeletons, as well as a great variety of other chemical substances voided by the bat, among which are urea and potassium phosphate. The composition is fairly constant, as shown by the analyses of samples Nos. 472, 503 (Table III), 751, 780, 854, 876, 879, 880, 881, 885, and 977 (Table IV):

TABLE I.—*Results of analyses of 11 samples of bat manure.*

	Nitrogen.	Total phosphoric acid.	Citrate-soluble phosphoric acid.
	Per cent.	*Per cent.*	*Per cent.*
Maximum	13.04	9.74	7.22
Minimum	9.21	2.96	2.61
Average	10.93	7.29	5.54

Besides these constituents, the fresh manure contains about 2.3 per cent potash, 3.5 per cent sulphur trioxid, small amounts of iron, alumina, lime, magnesia, and silica, and about 83 per cent of organic and volatile matter.

The nitrogen of the fresh manure is present as insoluble organic compounds (proteins, chitin), as soluble organic compounds (urea, etc.), and as ammonia and nitrates. In the above samples the nitrogen present as ammonia and nitrate averaged 39 per cent of the total nitrogen, although it varied between 4.9 and 73.2 per cent. The absolutely fresh manure doubtless contains practically no nitrate and ammonia, but under certain conditions they are formed rather quickly. In absolutely fresh bat manure, urea and insoluble nitrogenous compounds carry most of the nitrogen.

A certain amount of this fresh material exists in all caves still inhabited by bats, the quantity being determined by the number of bats and the conditions for conservation obtaining in the cave. In most caves the surface inch or 3 inches of the deposit is fresh manure, while in certain dry caves where decomposition is slow there is 3 or more feet of undecomposed guano in some compartments.[1] In other caves the fresh material occurs mainly in piles where the bats congregate.

As the fresh bat manure is exposed to water entering the cave, the soluble constituents are leached down into the rock (generally limestone) forming the floor of the cave. The soluble phosphates and sulphates react with the lime, forming the less soluble calcium phosphates and sulphate, while the potash and nitrates disappear in the drainage water. As the manure decomposes under bacterial action, the organic matter is oxidized, with the formation of carbon dioxid, ammonia, and nitric, sulphuric, and phosphoric acids. The carbon dioxid and some ammonia pass off into the air, while the phosphoric, sulphuric, and nitric acids, leached into the underlying stratum, react with the lime. When bacterial decomposition and leaching are not complete, the resulting product is decomposed guano; when they are complete, the resulting product is a phosphatic guano.

Decomposed guano.—The decomposed guano is generally brown in color and pulverulent, with a much higher volume weight than bat manure but lower than ordinary soil. It often contains lumps of gypsum, organic matter, or fragments of carbonate of lime. The composition is intermediate between that of the fresh manure and the phosphatic guano. It contains considerable organic matter and gypsum. As this is not a well defined material, no maximum and minimum figures can be given for the percentages of nitrogen and

[1] All black surface material high in organic matter is not fresh bat manure. In some caves the surface 1, 2, 3, or 6 inches of material with some undecomposed insects' wings contains only 2, 3, or 4 per cent of nitrogen. This shows fairly rapid decomposition of the material in moist caves.

phosphoric acid, but as a rule it contains 1 to 2 per cent of nitrogen, 10 to 20 per cent total phosphoric acid, and 3 to 10 per cent of citrate-soluble phosphoric acid. Small amounts of nitrates and water-soluble potash are often present. Samples Nos. 458, 497, 733, and 734 are representative of this class of guano.

Phosphatic guano.—Phosphatic guanos represent what may be called the end product of the various reactions and conditions which produce the decomposed guanos. Practically all organic matter has been oxidized, leaching has carried away all the potash, gypsum, and nitrates, and the monocalcium and dicalcium phosphates have been converted into tricalcium, ferric, or aluminum phosphates. The phosphatic guano, though somewhat similar in appearance to the decomposed guano, has a greater volume weight and is generally more gritty in texture and lighter in color. Sometimes the color is red, owing to the presence of much iron, but it is more generally light brown or gray. Phosphatic guano contains practically no nitrogen and consists of the insoluble phosphates of lime, iron, or alumina, mixed with siliceous impurities. The total phosphoric acid content is high unless the amount of siliceous impurities is high. Samples Nos. 500, 501, 504, and 509 are of this type. This material is physically and chemically similar to old, leached bird guano.

CONDITIONS AFFECTING THE COMPOSITION OF THE DEPOSITS.

The great variation in the guano in the same and different caves can not be well understood without considering the various conditions affecting the material. The composition of a guano is determined by its age, the amount of water entering the cave, the intrusion of soil from without, and the composition of the limestone or rock forming the floor of the cave.

The age of the deposit is of slight importance in determining the nature of the material except as it affects the completeness of other modifying influences.

The amount of water entering the cave doubtless affects the material more than any other condition. A cave where no water enters and where the atmosphere is yet sufficiently humid to promote bacterial decomposition is likely to contain a guano high in nitrates, potash, phosphoric acid, and soluble salts [1] or a product richer than the fresh manure, owing to the decomposition of the bulky organic matter. Absolutely dry conditions, such as obtain at the Peruvian guano deposits, where moisture is insufficient for much bacterial decomposition, will most probably produce a guano of practically the same composition as the original material.

Neither of these extremes exist in Porto Rico, as surface or percolating water enters all the caves at times. Where material has

[1] Sample No. 881 approaches this material.

been exposed to a flow of water through the mouth of the cave or through holes in the roof, it contains very little soluble material. Where only a small amount of water percolates through the rock, the guano may contain considerable soluble phosphates, gypsum, some nitrates, and ammonia. In some cases a leached phosphatic guano is enriched, possibly only temporarily, by the infiltration of soluble phosphates, nitrogen, and gypsum from other parts of the deposit. The accumulations of gypsum which sometimes occur in certain parts of a deposit are evidently due to the evaporation of leachings from other parts of the deposit.

Aside from the translocation and removal of soluble materials, water affects the composition of a guano by influencing the course of bacterial decomposition. In some instances quantities of fresh manure have become so saturated with water as to undergo an anaerobic bacterial decomposition, probably similar to that resulting in the formation of peat. Similar material is formed when a layer of fresh manure becomes covered with a crust of carbonate of lime or a slide of other guano. This material is not very common, but is easily recognized, as it is black rather than brown in color and shrinks enormously on drying. It contains a large amount of organic matter and considerable nitrogen. Samples Nos. 502 (Table III) and 786 and 982 (Table IV) represent this material.

Occasionally earth is carried in through the mouth of the cave or through holes in the roof which, becoming admixed with the guano, renders it of little value. Samples Nos. 802, 804, 805, 813, 919, 1007 (Table IV) are representative.

The character of the rock forming the cave determines largely the composition of the leached or phosphatic guanos. Where the cave is formed in pure limestone and there are no intrusions of soil, the phosphatic guano consists chiefly of tricalcium phosphate. This is true of some of the leached bird guanos found on Mona Island. Where the rock, however, contains considerable iron, alumina, and silica, or these elements are brought in by water, the phosphatic guano may consist largely of phosphates of iron and alumina with siliceous impurities, as shown by the analyses of samples Nos. 501, 504, 505, and 509 (Table III).

VARIATION OF MATERIAL IN THE CAVE.

Most caves contain a large number of different kinds of guano, varying from the fresh bat manure to the leached phosphatic guano. While the general classes of material are more or less apparent to the eye, little can be told about the percentages of the fertilizing elements from the appearance.

Hardly any rule can be given concerning the variation in guano in different parts of a cave. In some cases the guano below the fresh

surface is fairly uniform at different depths, while in other cases it varies considerably. The same is true of the lateral variation. In some caves the material in different caverns or compartments is fairly uniform, while in others it is not. Generally the material is likely to be more uniform at different depths than in different parts of a cave. Analyses illustrating these points are afforded by samples Nos. 497 to 500, 772, 774, 775, 777 to 779, 788 to 791, 792 to 794, 843 to 845, 848 to 850, and 856 to 859, as may be seen by referring to a description of the samples in Table IV.

CHEMICAL ANALYSES OF SAMPLES.

METHODS OF ANALYSIS.

In preparing the samples for analysis and for vegetation tests, all were passed through a 1-millimeter sieve, except the fresh bat manure. This could be done by pulverizing without grinding. Occasional pieces of limestone or stony concretions not readily pulverized were discarded. In this way, a fair sample of the utilizable material was obtained, as the large lumps of nonpulverulent material have little fertilizing value and should be screened out before transporting the guano from the cave.

The usual analytical methods of the Association of Official Agricultural Chemists were used when possible. Samples containing much organic matter were ignited with magnesium nitrate before determining the total phosphoric acid. Lime was determined by the Glaser method as modified by Jones.[1]

The total nitrogen in most samples was determined by the Kjeldahl method modified for nitrates, as nearly all samples contained more or less nitrate. The nitrogen present as ammonium salts was determined in a water solution of the guano by direct distillation with sodium hydroxid. Nitrates were then determined in the same solution by distillation with the further addition of zinc and iron. The results for ammonia thus obtained may sometimes be slightly in excess of the true values, as the sodium hydroxid may have attacked organic nitrogenous compounds, but they are accurate enough for practical purposes.

All percentages are calculated on a moisture-free basis. It should be borne in mind that the ordinary air-dried guanos contain 3 to 15 per cent of moisture, and that the percentages calculated on an air-dry basis would therefore be somewhat lower. In the ordinary cave, the guano, before air-drying, contains a very high percentage of moisture, as may be seen from Table II, which gives the moisture content of different guanos from two caves of about average dryness.

[1] Wiley, H. W. Principles and Practice of Agricultural Analysis. Easton, Pa., 1908, vol. 2, 2. ed., p. 236.

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TABLE II.—*Moisture content of guanos in the cave.*

Laboratory number.	Moisture content.	Laboratory number.	Moisture content.
	Per cent.		*Per cent.*
497	43.12	504	8.47
498	43.40	505	16.34
499	29.36	506	17.96
500	26.10	507	20.00
501	25.00	508	12.22
502	55.92	509	14.64
503	44.62		

COMPLETE ANALYSES OF REPRESENTATIVE GUANOS.

Before the systematic survey of the caves was commenced, a number of samples were subjected to a complete analysis to gain an idea of their general composition and to find whether the amount of citrate-soluble phosphoric acid [1] varied with the quantity of any other constituents, as iron and alumina, lime, or sulphates. The analyses are given in Table III.

The method of calculating the monetary value of the samples in Tables III and IV is described in a subsequent part of this report.

[1] Citrate-soluble phosphoric acid in this bulletin refers to all phosphoric acid soluble in neutral ammonium citrate, i. e., water-soluble phosphoric acid plus that insoluble in water but soluble in ammonium citrate.

TABLE III.—*Complete analyses of representative bat guanos.*

Laboratory No.	Name or location of cave.	Description.	Total nitrogen (N).	Total phosphoric acid (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.	Water-soluble potash (K_2O).	Lime (CaO).	Magnesia (MgO).	Iron (Fe_2O_3).	Alumina (Al_2O_3).	Sulphur (SO_3).	Volatile matter.	Insoluble matter, sand, etc.	Approximate value per dry ton.[a]
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
263	Aguadilla	Mixed lot, with some carbonate of lime.	0.40	7.77	0.28	2.92	0.64	30.49	Trace.	3.04	0.33	18.97	27.64	8.94	$3.69
321	Cabo Rojo		1.63	14.47	.53	3.24	....	5.82	Trace.	6.03	6.86	7.37	28.98	28.55	7.17
374	Arecibo		.52	12.68	.82	2.96	.96	22.45	0.20	4.27	4.44	19.54	22.02	16.68	5.55
375	Las Marias		.66	18.55	1.10	3.89	.18	13.72	1.15	5.33	5.47	17.54	28.32	12.97	5.58
376	do	Mostly seeds	3.23	4.35	.46	2.42	.25	1.74	.27	10.58	2.37	10.95	56.67	16.44	8.54
415	Cabo Rojo		.66	20.73	.41	1.13	.23	15.18	.17	5.17	8.61	2.80	26.29	17.83	6.53
447	Vega Baja		1.06	26.18	.33	10.45	.42	34.36	.10	4.90	1.11	3.06	19.04	6.54	9.35
458	San Germán		1.32	13.85	.51	5.29	.77	5.24	.05	4.33	2.89	17.10	38.69	14.53	8.95
460	Cabo Rojo, Hacienda Margarita.		.97	13.56	0	6.85	.32	19.86	.20	5.34	3.65	5.98	32.30	20.01	4.16
[b] 472	Lares	Fresh bat manure	10.25	6.95	2.82	6.43	3.85	2.36	1.40	.38	0	3.00	83.65	.16	23.90
497	"Ancones," Barrio Ancones, San Germán.	Surface foot	1.46	7.75	.90	1.37	.25	25.51	0	3.35	.23	23.95	32.85	4.01	4.73
498	do	Second foot	1.43	10.50	.78	.80	.06	19.45	0	4.60	4.46	19.31	31.86	5.62	5.65
499	do	Third foot	.27	28.08	.24	1.37	.10	7.49	0	6.27	15.77	7.81	21.13	10.84	7.66
500	do	Fourth foot	.28	31.20	.30	4.97	.47	6.75	0	5.03	19.52	2.24	27.27	5.87	11.01
501	do	Sixth foot	.33	26.51	.40	1.22	.13	3.78	0	7.56	12.90	2.32	17.42	25.37	5.30
502	do	Black peaty material from pocketlike depression covered with other guano.	5.35	13.06	.39	2.08	.31	13.12	0	5.97	2.00	1.46	46.38	16.97	12.19
[c] 503	"Francisco Quiñones," San Germán.	Fresh bat manure near cave mouth.	11.73	7.42	2.40	5.04	1.57	4.56	1.03	.78	.49	3.80	82.63	1.39	26.75
504	do	Ninth foot near center of cave	.18	21.45	Trace.	0	.34	.74	Trace.	11.33	7.77	....	14.40	42.70	.70
505	do	First foot near center of cave	.56	24.43	Trace.	0	.13	2.48	Trace.	15.00	8.44	0	15.35	31.62	2.23
506	do	Gray-black, dusty material, first foot just outside cave mouth.	.59	10.18	Trace.	3.28	.29	22.77	1.89	4.61	2.62	6.97	24.50	24.00	2.28
507	do	Fourth foot near cave mouth	.80	19.04	0.19	3.94	.28	8.18	.57	8.46	8.44	5.56	24.30	23.68	7.40
508	do	Seventh foot near cave mouth	.64	29.31	Trace.	3.81	.22	2.15	Trace.	13.25	13.08	0	19.51	18.28	2.09
509	do	First foot near center of cave, distant from 505.	.38	22.91	Trace.	0	.23	2.02	0	15.20	6.15	0	15.92	38.14	1.68
733	Cayey		.76	19.10	1.55	10.72	Trace.	27.62	Trace.	2.42	1.21	16.16	28.94	7.48	13.74
734	do		.84	18.30	1.04	8.11	Trace.	21.19	Trace.	4.28	3.37	10.42	27.72	16.11	8.82

[a] Based on prewar values of fertilizer constituents. See page 54 for method of determining values.
[b] No. 472 contains 0.78 per cent of nitrogen as ammonia and 0.31 as nitrate.
[c] No. 503 contains 1.57 per cent of nitrogen as ammonia and 1.23 as nitrate.

It can be seen that no one constituent showed any regular variation with any one other constituent in all the samples. The amount of citrate-soluble phosphoric acid did not show any correspondence with the amount of nitrogen, potash, sulphates, lime, iron, or alumina. All constituents varied greatly in the different samples except magnesia, which was uniformly low, and potash, which was practically negligible in all except the two samples of fresh bat manure. Sample No. 263 contained 15.68 per cent of carbonate of lime, this being the only sample with an appreciable amount of carbonate.

PARTIAL ANALYSES OF SAMPLES TAKEN IN SURVEY OF DEPOSITS.

The samples taken in the course of the survey of the different deposits were, as a rule, analyzed only for total nitrogen and the various forms of phosphoric acid. When from a preliminary examination it seemed worth while nitric and ammoniacal nitrogen were determined.[1] Descriptions of the different samples and the results of the partial analyses are given in Table IV.

TABLE IV.—*Analyses of guanos, with their approximate values.*

Laboratory No.	Name or location of cave.	Description.	Total nitrogen (N).	Nitrogen as ammonia.	Nitrogen as nitrate.	Total phosphoric acid. (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.	Approximate value per dry ton.
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
751	Barrio Monte Grande, San Germán.	Fresh bat manure...	10.81	2.04	1.15	6.51	....	5.45	$26.89
	"La Tuna," Barrio La Tuna, Cabo Rojo:								
772	Section A..........	Surface to 2 in.......	2.01	.09	.45	8.43	0.95	3.43	7.13
773	Do............	.....do..............	4.28	.26	.59	12.07	2.10	5.74	13.35
774	Do............	2 to 14 in............	.88	....	....	4.20	.76	2.08	3.84
775	Do............	14 to 26 in...........	1.12	....	....	3.94	.78	1.01	3.25
776	Section B..........	3 to 14 in............	.72	....	....	21.82	.29	5.43	6.87
777	Section C..........	Surface to 1 in.......	6.63	.44	.42	5.33	.76	2.11	11.55
778	Do............	1 to 12 in............	.46	....	....	16.88	Trace.	3.16	4.08
779	Do............	12 to 18 in...........	.23	....	....	11.88	Trace.	3.16	3.62
780	Section D..........	Surface to 3 in.......	9.65	.42	3.81	5.21	2.39	4.18	27.69
783	Do............	Surface to 12 in. (sides).	1.02	....	....	17.08	.25	5.83	7.87
784	Do............	12 to 36 in. (sides)...	1.25	....	....	23.90	.12	11.06	10.87
785	Section A..........	Mixture of 772, 774, and 775.	.89	....	....	4.89	.89	2.19	3.69
786	Do............	2 to 38 in............	5.91	.02	.35	6.64	.17	1.04	7.45
787	Cabo Rojo............	First 3 ft. of deposit.	.11	....	....	17.38	Trace.	3.48	3.48
	"Los Chorros," Barrio Cotui, San Germán:								
788	Section C..........	First 8 in............	.83	....	....	9.44	.16	2.25	3.91
789	Do............	Second 8 in..........	.51	....	....	13.09	.24	1.95	2.97
790	Do............	Third 12 in..........	.36	....	....	19.43	.23	2.55	1.50
791	Do............	Fourth 8 in..........	.22	....	....	15.99	.29	1.29	1.73
792	Section A..........	First 9 in............	1.37	....	....	24.24	.24	5.53	8.27
793	Do............	Second 12 in.........	.99	....	....	24.87	.26	6.90	10.68
794	Do............	Third 14 in..........	.72	....	....	23.29	.17	4.56	6.00
795	Section B..........	4 to 18 in............	.96	....	....	21.52	.20	1.75	3.67
796	Section F..........	3 to 40 in. (fine material lodged between disintegrated stone).	.15	....	....	21.37	0	0	.51

[1] Nitric and ammoniacal nitrogen were not determined in samples of less than 1.50 per cent total nitrogen except in special cases.

TABLE IV.—*Analyses of guanos, with their approximate values*—Continued.

Laboratory No.	Name or location of cave.	Description.	Total nitrogen (N).	Nitrogen as ammonia.	Nitrogen as nitrate.	Total phosphoric acid. (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.	Approximate value per dry ton.
	"Los Chorros," etc.—Con.		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
797	Section C	Mixture of surface 3 in. near 788 to 791.	2.27	0.06	0.25	11.16	0.51	4.21	$3.51
	"Guaniquilla No. I," Barrio Guaniquilla, Cabo Rojo:								
798	Section A	Surface to 3 ft	.21	......	......	17.25	Trace.	3.02	1.11
799	Section C	Surface to 6 ft	.88	......	......	31.92	.71	8.41	12.41
	"Guaniquilla No. II," Barrio Guaniquilla, Cabo Rojo:								
800	Section A	Surface to 2 ft	.44	......	......	19.13	Trace.	3.85	4.73
801	Section B	.....do	.68	......	......	18.67	Trace.	6.03	7.39
802	Section C	.....do	.03	......	......	2.21	......	.05	......
804	Hacienda Juanita, between Mayaguez and Las Marías.	......	.06	......	......	3.65	......	......	......
805	Do	......	.07	......	......	5.10	......	......	......
	"Boquilla," Barrio Tierras Nuevas, Campo Alegre:								
806	Section A	Surface to 6 in	1.38	......	......	16.07	.43	5.43	4.69
807	Do	6 to 30 in	.25	......	......	38.57	.34	5.81	2.81
808	Section B	Surface to 3 ft	1.32	......	......	12.72	.25	3.88	6.52
809	Section C	Surface to 6 ft	4.28	.02	.54	13.48	.66	5.63	5.96
810	Do	6 in. to 6½ ft	.21	......	......	32.35	.79	5.68	3.66
811	Section D	Surface to 3 ft	3.28	.04	.24	18.53	......	5.60	6.90
812	"Alta Gracia," Barrio El Coto, Manati.	Surface to 3 in	2.08	.03	.47	.50	......	......	3.22
813	Do	3 to 15 in	.59	......	......	.50	......	......	1.18
	"La Laguna," Barrio El Coto, near Campo Alegre:								
814	Section A	Surface to 12 in	.47	......	......	13.36	Trace.	2.39	3.33
815	Do	12 to 36 in	.12	......	......	9.97	Trace.	2.27	2.51
816	Section B	Surface to 6 ft	.52	......	......	20.24	Trace.	4.69	4.68
817	"Los Santos," Barrio El Coto, Manati.	Surface to 24 in	.14	......	......	22.82	.56	2.61	2.89
818	"Central Carmen," Barrio Rio Abajo, Vega Baja.	Surface to 3 ft	.34	......	......	36.77	1.06	8.62	10.24
819	"Miranda," Barrio Rio Arriba, Vega Baja.	.....do	4.07	.43	1.74	8.25	2.34	6.56	17.86
820	Aguas Buenas	Surface material	1.03	......	......	5.08	Trace.	2.58	4.64
821	Do	First 2½ ft. from dry part of cave.	1.58	......	......	11.02	.64	4.81	7.97
	"La Oscura," Barrio Rosario, San Germán:								
824	Section A	Surface to 3 ft	.21	......	......	15.86	Trace.	.51	.74
825	Section C	Surface to 2 ft	.18	......	......	3.63	Trace.	.66	.92
	"El Murciélago," Barrio Rosario, San Germán:								
826	Section A	Surface to 3 ft	.83	......	......	5.82	.27	4.07	5.73
827	Section B	.....do	.41	......	......	4.75	.14	2.06	2.88
828	Do	Surface to 2 in	4.15	.05	.83	6.49	.37	2.53	10.80
829	Do	2 to 50 in	.36	......	......	6.76	.08	5.50	6.22
830	Section C	Surface to 12 in	.53	......	......	2.97	.07	2.29	3.35
	"El Colorado," Barrio Rosario, San Germán:								
831	Section A	Surface to 36 in	.08	......	......	4.72	......	1.15	1.31
832	Section B	Surface to 12 in	.07	......	......	4.70	......	1.03	1.17
833	Section C	Surface to 9 ft	1.01	.04	.95	1.46	......	1.12	5.10
834	Section D	Surface to 24 in	.06	......	......	3.01	......	......	......
	"El Convento," Barrio El Cedro, Peñuelas:								
841	Section A	Surface to 3 in	4.42	.05	3.40	16.66	.29	4.44	18.66
842	Section B	.....do	3.62	.07	2.20	14.83	......	3.08	15.03
843	Do	3 in. to 5¼ ft	1.53	.01	1.30	24.59	......	3.11	8.57
844	Do	3 in. to 3¼ ft	1.30	.03	1.06	26.52	......	3.00	7.57
845	Do	3 in. to 5¼ ft	1.51	.02	1.03	20.88	......	4.02	8.68
846	Do	Mixture of 843, 844, and 845.	1.93	.04	1.18	21.52	......	2.48	9.10

TABLE IV.—*Analyses of guanos, with their approximate values*—Continued.

Laboratory No.	Name or location of cave.	Description.	Total nitrogen (N).	Nitrogen as ammonia.	Nitrogen as nitrate.	Total phosphoric acid. (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.	Approximate value per dry ton.
	"El Convento," etc.—Contd.		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
847	Section C	Surface to 3 in	6.29	0.07	1.17	7.77	0.79	4.63	$14.64
848	Do	3 in. to 4¼ ft	1.81	.12	1.38	23.45		4.02	10.33
849	Do	do	.87			25.01		9.36	11.10
850	Do	3 in. to 5¼ ft	.94			22.50		5.01	6.89
851	Do	Mixture of 848, 849, and 850.	1.42	.05	.74	25.62		7.29	8.73
	"Mapancha," Barrio El Coto, Peñuelas:								
852	Section A	Surface to 3 ft	5.06	.47	2.93	9.39	1.88	8.34	24.79
853	Section B	Surface to 18 in	2.76	.04	.88	10.37	.64	1.32	8.32
854	Section C	Surface to 6 in	9.21	.38	2.10	8.74	1.06	5.89	23.38
	"Pascual," Barrio El Cedro, Peñuelas:								
855	Section A	Surface to 2½ ft	10.54	1.31	.22	8.81	.64	1.88	18.60
856	Section B	Surface to 7½ ft	1.55			17.79		2.70	5.80
857	Do	Surface to 5 ft	1.86	.04	1.53	21.37		4.03	10.60
858	Do	Surface to 5½ ft	3.46	.06	3.28	24.58		5.91	20.97
859	Do	Surface to 4 ft	1.74	.04	1.29	22.12		3.34	9.07
860	Do	Mixture of 856, 857, 858, and 859.	2.35	.03	2.29	19.29		2.94	13.54
	"El Jaguey," in range of hills north of Guanica Centrale:								
876	Section A	Surface to 3 in	9.91	3.10	4.15	7.75		5.19	38.68
877	Section B	Surface to 2 ft	.52			17.03		2.35	3.39
	"Santa Rita," hills south of Santa Rita station:								
878	Section A	Surface to 3 ft	7.58	1.34	4.19	10.14		6.12	33.00
879	Section B	Surface to 6 ft	12.16	3.58	4.33	9.74		6.76	46.13
880	Section C	Surface to 3 ft	10.90	2.74	3.20	8.16		5.88	38.78
881		Mixture of 878, 879, 880.	13.04	3.60	4.60	8.94		6.25	47.60
	"El Horno," in range of hills north of Guanica Centrale:								
882	Section A	Surface to 12 in	.17			6.98		1.15	1.49
883	Section B	do	.17			21.60		0	.34
884	"La Ballena," at foot of hills to south of Guanica Centrale, section A.	Surface to 4 ft	2.47	.04	.47	8.38		3.95	7.95
885	"Ventana," Hacienda La Ventana, Guayanilla.	Surface to 3 in	10.60	1.14	2.12	2.96		2.61	23.72
	"Caja de Muertos No. I," northeast of lighthouse:								
886	Section I	Surface to 6 ft	.57			33.44		11.51	12.65
887	Section II	Surface to 2½ ft	1.32			32.23		4.75	7.39
888	Section III	Surface to 6 ft	.83			31.12		9.57	11.23
889		Mixture of 886, 887, and 888.	1.01	.03	.05	31.63		10.79	5.13
890	"Caja de Muertos No. II," northeast of lighthouse.	Surface to 3 ft	.21			14.58		4.58	5.00
891	"La Majina," Barrio Límon, section A.	Surface to 4 ft	.21			5.03		1.63	2.05
910	Bayamón		.31			2.38		.66	1.28
	"Lucero," Barrio Cabachuelas, Morovis:								
911	Section A	Surface to 2 ft	6.15	.01	.10	13.71		3.02	9.50
912	Section D	Surface to 3 ft	.62			19.63		1.95	1.44
913	Section A	2 to 4 ft	.34			23.78		.77	1.45
914	Section B	Surface to 6 ft	.08			10.09		.85	1.01
915	Section C	Surface to 5 ft	.33			6.17		.60	1.26
	"Achotillo," Barrio Cabachuelas Morovis:								
916	Section A	Surface to 3½ ft	.08			13.65		1.32	.30
917	Section B	Surface to 4 ft	.10			4.03		1.12	.32

TABLE IV.—*Analyses of guanos, with their approximate values*—Continued.

Laboratory No.	Name or location of cave.	Description.	Total nitrogen (N).	Nitrogen as ammonia.	Nitrogen as nitrate.	Total phosphoric acid. (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.	Approximate value per dry ton.
	"San Miguel," Barrio Cabachuelas, Morovis:		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
918	Section A	Surface to 8 ft. in southeast corner.	0.90			4.41		1.52	$3.32
919	Do	Floor, 5½ ft. below 918.	.11			1.19		.21	.43
920	Section B	Floor, surface to 1 ft.	.19			4.69		2.90	3.28
	"La Chiquilla," Barrio Cabachuelas, Morovis:								
921	Section A	Surface to 2 ft	.13			1.82			
922	Do	Surface to 3 ft	.20			2.26		1.00	1.40
	"Oscura," Barrio Cabachuelas, Morovis:								
923	Section A	3 in. to 3¾ ft	.73			33.64		6.64	3.14
924	Do	3 in. to 4¾ ft	.51			37.44		10.77	11.79
925	Section B	3 in. to 6¼ ft	.15			30.21		2.70	3.00
926	Section C	3 in. to 5¼ ft	.16			8.87		1.25	1.57
927	Do	3 in. to 4¾ ft	.25			36.90		8.11	8.61
928	Sections A, B, C	Surface to 3 in	2.75	0.05	0.19	12.09		3.76	5.16
929	"Capa Prieta," Barrio Cabachuelas, Morovis.	Surface to 6 in	.31			9.92		2.10	2.72
930	Do	6 in. to 2 ft	.11			6.12		1.00	1.22
	"Pablo Clas," Barrio Cabachuelas, Morovis:								
931	Section A	Surface to 7 ft	.80			27.57		9.08	10.15
932	Section B	do	.89			28.66		6.99	7.23
	"Toronja," Barrio de Cabachuelas de Torrecilla, Morovis:								
933	Section A	Surface to 2 ft	8.92	.01	.07	5.78		1.62	10.78
934	Section B	3 in. to 2¼ ft	.48			22.84		1.26	2.22
935	Sections B and C	Upper 3 in	3.32	.10	1.59	6.81		4.17	13.53
936	Section C	3 in. to 3¾ ft	1.13		.79	21.87		6.80	11.47
	"Cerro Hueco," Barrio de Cabachuelas de Torrecilla, Morovis:								
937	Section A	Surface to 2 ft	.78			14.11		5.24	6.80
938	Section B	Surface to 18 in	1.59	.02	1.14	12.55		3.74	9.09
939	Section C	Surface to 2 ft	3.08	.13	.34	24.48		6.45	9.19
940	"De los Puercos," Barrio Cabachuelas, Morovis.	Surface to 18 in	.21			5.59		.80	1.22
941	"Alta," Barrio Cabachuelas, Morovis.	Surface to 2 ft	3.01	.31	.36	5.29		3.40	8.42
	"Archilla," Barrio Cabachuelas, Morovis:								
942	Section A	Surface to 3 ft.[a]	.59			23.88		2.42	3.60
943	Do	do.[b]	.68			23.39		2.58	3.70
944	Section C	Surface to 18 in.[b]	.72			22.62		2.56	4.00
945	Do	do.[a]	1.28			21.11		9.71	13.33
946	Section D	Surface to 3 ft.[c]	.60			2.32		.64	1.84
947	"Escalera," Barrio Cabachuelas, Morovis.	Surface to 8 ft.[a]	.27			39.65		5.96	4.51
	"Convento," Barrio Hato Viejo Poniente, Ciales:								
952	Section A	Surface to 1 ft	2.34	.04	.12	7.49		2.87	5.68
953	Do	1 to 2 ft	.71			34.02		1.40	2.81
954	Do	Surface to 1 ft	.23			26.91		2.94	3.40
955	Section B	do	.18			29.53		1.50	.95
956	Section C (hole C–1)		.06			41.58		0	.12
957	Section C (holes C–3 to C–6).	Surface to 3 ft	.52			31.85		14.92	11.87
958	Section C (hole C–4)	Surface to 2 ft	1.06			4.05		2.77	4.89
959	Do	2 to 4 ft	.23			34.13		21.64	11.72
960	Section C (hole C–7)	Surface to 1 ft	.55			5.56		2.95	4.15
961	Section C (hole C–8)	do	.99			14.97		13.18	9.32

[a] Border of guano still in place.
[b] Guano turned over to extract intermediate black layer.
[c] Dirt through which passageway has been cut for pack horses to pass in and out of cave.

TABLE IV.—*Analyses of guanos, with their approximate values*—Continued.

Laboratory No.	Name or location of cave.	Description.	Total nitrogen (N).	Nitrogen as ammonia.	Nitrogen as nitrate.	Total phosphoric acid. (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.	Approximate value per dry ton.
	"La Gonzalez," Barrio Hato Viejo Poniente, Ciales:		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
962	Section A	Surface to 18 in	0.12			2.45		0.03	$0.27
963	Section B	Surface to 2 ft	.25			6.61		3.90	4.40
	"Clara," Barrio Sumidero, Aguas Buenas:								
964	Northwest section	Surface to 6 in	.37			5.72		2.20	2.94
965	Southeast section	do	.87			13.31		9.85	4.14
	"Oscura," Barrio Sumidero, Aguas Buenas:								
966	Section C	Surface to 1 ft	2.35	0.05	0.14	11.99		4.62	5.32
967	Section B	do	3.65	.05	.03	9.59		3.60	7.49
968	Sala IV	Surface to 3 in	2.21	.04	.08	6.28		3.95	6.52
969	Sala Grande	do	2.37	.03	.02	5.28		1.85	4.37
970	El Alto	do	3.26	.05	.12	8.78		4.04	5.97
	"Del Rio," Barrio Sumidero, Aguas Buenas:								
971	Chamber beyond "Charco Hondo."	Surface to 1 ft	2.01	.05	.21	7.99		5.44	5.35
972	Do	1 ft. to 18 in	.07			.82		.49	.73
973	"Biafara No. I," Barrio Miraflores, Arecibo.	Surface to 4 ft	.20			10.02		2.15	2.55
974	Do	4 to 10 ft	.14			25.81		2.76	3.04
975	Do	Mixture from pile at dwelling house.	.31			26.43		2.79	1.68
976	"Biafara No. II," Barrio Miraflores, Arecibo.	Surface to 1 ft	.17			2.28		1.42	1.76
	"Bernardo Méndez," Barrio Bayaney (Barroacal o Angeles), Hatillo:								
977	Section A	Surface to 3 ft	12.03	2.15	2.20	7.82		7.22	35.64
978	Do	3 to 9 ft	3.09	.78	1.39	26.69		21.84	33.58
	"Vilella," Barrio Yeguadilla, Hatillo:								
979	Section A	Surface to 6 in	.63			7.33		1.86	3.12
980	Do	6 in. to 4½ ft	.20			30.44		3.82	1.92
981	Section B	6 in. to 1 ft	.27			28.44		3.52	1.39
	"Ollo Oscuro," Barrio Santiago, Camuy:								
982	Sections A and C	Surface to 1 ft	9.44	.06	.40	10.22		7.43	14.19
983	Section A	1 ft. to 18 in	.78			12.37		10.28	11.84
984	Do	18 in. to 5 ft	.58			.99		.67	1.83
985	Section C	1 to 3 ft	.48			14.79		10.68	5.55
999	"Juan Encarnacion Cortés," Barrio Corrales, Aguadilla.	Surface to 3 ft	.53			Trace			1.06
1000	Property of Ludovino Suarez, Barrio Arenales, Aguadilla.	Surface to 2 ft	.24			10.20		1.59	2.07
1001	"California," Barrio Centro, Moca.	Surface to 4 ft	.34			32.61		9.21	9.89
1002	Do	Surface to 3 ft	.29			33.96		4.48	5.07
1003	Nos. I, II, and III, property of Mercedes Reinan, Barrio Corrales, Aguadilla.	Surface to 2 ft	.62			2.84		1.47	2.71
1004	"Honda," Barrio Caimital Bajo, Aguadilla.	Surface to 3 ft	.31			2.77		1.69	2.31
1005	Do	2 ft. to 3 ft	.42			1.19			.84
	Property of Antonio Herrera, Barrio Caimital Bajo, Aguadilla:								
1006	No. 1	Surface to 1 ft	.40			1.21		Trace	.80
1007	No. 6	do	.40			Trace			.80
1008	Property of Pablo Gonzáles, Barrio Camaseyes, Aguadilla.	do	.48			Trace			.96

TABLE IV.—*Analyses of guanos, with their approximate values*—Continued.

Laboratory No.	Name or location of cave.	Description.	Total nitrogen (N).	Nitrogen as ammonia.	Nitrogen as nitrate.	Total phosphoric acid. (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.	Approximate value per dry ton.
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
1009	Property of Tomás Torres, Barrio Corrales, Aguadilla.	.....do	0.68			2.62		1.54	$2.90
1010	Property of Pedro Roldan, Barrio Camaseyes, Aguadilla.	.....do	.39			3.84		2.86	3.64
1011	"Cuchilla," Barrio Cuchilla, Moca.	Surface to 2 ft	1.80	0.03	0.04	21.07		6.77	4.33
1012	Property of Rafael Domenech, Barrio Caimital Bajo, Aguadilla.	Surface to 1 ft	.50			6.39			1.00
1013	Property of Rafael Suárez, Barrio Centro, Moca.	.....do	.23			26.93		2.76	1.00
1014	Property of Gabriel Piñeiro, Barrio Coto, Isabela.	.....do	.24			3.17			3.65
1015	"Sin Fin," Barrio Arenales Bajos, Isabela.	.....do	.63			5.03			6.29
	"El Jobo," Barrio Arenales Bajos, Isabela:								
1016	Section A	.....do	.48			23.42		2.62	3.58
1017	Section B	.....do	.17			36.71		18.52	18.86
1018	Do	.....do	.74			31.85		2.97	2.12
	"Murciélago," Barrio Galateo Alto, Isabela:								
1030	Section A (subsection 1).	Surface to 2 ft. intact.	.09			3.69		.24	.42
1031	Section B (subsection 2).	Surface to 3 ft	.14			19.85		2.81	3.09
1032	Section B (subsection 3).	Surface to 6 in	2.15	.02	.02	21.94		2.28	4.55
1033	Section C (subsection 5).	Surface to 2 ft	.15			31.00		1.44	1.74
1034	Section D (subsection 5).	Surface to 3 ft. intact.	.57			5.62		1.50	2.67
	Property of Juan Eusebio Acevedo, Barrio Galateo Alto, Isabela:								
1035	Section A	4½ to 7½ ft	.38			25.35		4.23	4.99
1036	Do	Surface to 4½ ft	.62			18.88		9.33	10.67
1037	"Juan Bautista Perez," Barrio Planas, Isabela.	Surface to 2 ft	.22			36.44		1.94	2.388
1038	Do	Surface to 3 ft	.49			24.64		3.34	4.32
	"Chito Perez," Barrio Planas, Isabela:								
1039	Section III	12 to 15 ft	1.13			19.35		5.06	7.32
1040	Sections III and IV.	Surface to 3 ft	1.53			28.60		5.52	8.58
1041	Section II	.....do	.29			30.22		2.99	3.57
1042	Sections III and IV.	Surface to 10 ft	.27			28.90		1.25	1.79
1043	"Pajita," Barrio Callejones, Lares.	Surface to 3 ft	.08			17.97		1.93	2.09
1044	Do	3 to 6 ft	.44			4.68		.94	1.82
1045	"Sol," Barrio Callejones, Lares; main (north) mouth.	Surface to 1 ft. intact.	.76			6.14		1.09	2.61
	"Los Cruzes," Barrio Callejones, Lares:								
1046	Sections II and III.	Yellow earth	.14			6.23		4.43	4.71
1047	Far end of Section I	White nodules inclosed in guano.	.08			35.67		28.66	28.82
1048	Section III	Surface guano	.31			23.25		4.72	5.34
1049	Far end of Section I	Surface to 3 ft	.38			21.70		15.76	16.52
1050	Property of José Maria Girao (or Jurant), Barrio Lares, Lares; end of main compartment below rock.	3-ft. layer	.09			2.81		1.47	1.65

TABLE IV.—*Analyses of guanos, with their approximate values*—Continued.

Laboratory No.	Name or location of cave.	Description.	Total nitrogen (N).	Nitrogen as ammonia.	Nitrogen as nitrate.	Total phosphoric acid. (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.	Approximate value per dry ton.
	"Jesus Torres," Barrio Lares, Lares:		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
1051	Section A	Loose guano	1.51	0.15	0.66	24.22		4.84	$8.78
1052	Section B		1.13			20.87		1.75	4.01
1053	"Cerro de José Cruz," Barrio Lares, Lares; mouth of cave.	Surface to 1 ft	.75			1.52		.42	1.92
1072	"Clara" and "Oscura," Barrio Guayabal, Juana Diaz; sections I, III, and V.	Surface to 2 ft	.33			4.83		3.01	3.67
1073	"Callo," Barrio Villalba Arriba, Juana Diaz.	Surface to 1 ft	5.69	.06	.73	4.98		2.58	10.64
	"Naranjo," Barrio Naranjo, Juana Diaz:								
1074	Section A	Surface to 6 in	1.96	.04	.11	5.12		3.80	6.21
1075	Section B	Surface to 3 ft	1.70			Trace.			3.40
	"Los Santos," Barrio Vega Redonda, Comerio:								
1077	Section A	Surface to 3 ft	.62			10.36		4.49	6.73
1078	Section B	do	2.14	.04	.34	15.28		5.42	8.70
	"La Mora" or "Iglesia," Barrio Vega Redonda, Comerio:								
1079	Section A	do	2.00	.03	.75	7.26		3.61	7.95
1080	Section B	do	2.34	.02	.26	14.68		3.16	6.34
1081	Section C	do	1.69			16.98		8.46	11.84
1082	"Guaraguáo," Barrio Vega Redonda, Comerio.	Surface to 2 ft	.97			4.63		2.16	4.10
1104	"Flori," Barrio Pueblo Viejo, Pueblo Viejo.		1.22			19.94		9.99	12.43

Determinations were also made of the water-soluble potash in samples which, on account of their character or location, were likely to contain appreciable amounts. The results are given in Table V.

TABLE V.—*Water-soluble potash in certain guanos.*

Laboratory number.	Water-soluble potash (K_2O).	Laboratory number.	Water-soluble potash (K_2O).	Laboratory number.	Water-soluble potash (K_2O).	Laboratory number.	Water-soluble potash (K_2O).
	Per cent.		*Per cent.*		*Per cent.*		*Per cent.*
773	0.78	833	Trace.	855	1.59	881	4.15
777	.23	841	1.56	858	1.58	885	.73
780A	1.34	842	2.82	860	1.29	935	.97
786	.43	846	1.36	876	1.83	938	.28
799	.75	851	.84	878	2.71	977	3.22
819A	1.83	852A	3.90	879	3.48	978	.76
828	1.48	854	.84	880	4.18	982	Trace.

The potash in the other samples, with possibly a few exceptions, can be taken as negligible. Table III showed about the quantity of potash that could be expected in the ordinary guano.

It is hardly necessary to point out that some of the samples in Tables III, IV, and V represent valuable material and others practically worthless deposits. The maximum percentages of the fertilizing constituents found in the 247 samples analyzed were as follows: Total nitrogen 13.04 per cent, nitrogen present as ammonia 3.60 per cent, nitrogen present as nitrate 4.60 per cent, total phosphoric acid 41.58 per cent, water-soluble phosphoric acid 2.82 per cent, citrate-soluble phosphoric acid 28.66 per cent, water-soluble potash 4.18 per cent. The minimum figures found for the different constituents were practically zero. It will be noted that in many guanos most of the nitrogen is present as ammonia or nitrate. As was to be expected, the samples of best material came as a rule from caves in the drier parts of the island.

Samples Nos. 886 to 890 from the small island of Caja de Muertos were doubtless formed by birds rather than bats. Many of the analyses reported in Tables II and IV are similar to those of leached bird guanos from Mona Island, as may be seen from the analyses in Table VI.

TABLE VI.—*Analyses of guano deposits from Mona Island.*

Laboratory number.	Total phosphoric acid (P_2O_5).	Citrate-soluble phosphoric acid.	Total nitrogen (N).	Calcium sulphate ($CaSO_4$).	Laboratory number.	Total phoric acid (P_2O_5).	Citrate-soluble phosphoric acid.	Total nitrogen (N).	Calcium sulphate ($CaSO_4$).
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
573	28.71	13.85	0.25	34.37	593	18.00	3.37	0	51.48
574	26.36	4.76	.15	7.46	594	17.39	3.58	0.06	55.93
575	14.38	2.26	.08	.43	595	37.52	23.10	0	21.59
576	4.68	1.60	.04	5.20	596	6.30	2.39	0	64.29
577	32.25	12.96	.11	22.29	597	1.87	.11	.06	Trace.
578	45.41	5.96	.17	.82	598	.85	0	.36	Trace.
579	29.14	2.63	.08	1.29	641	25.85	5.57		25.11
580	35.52	4.97	.30	23.67	642	37.25	7.52		6.13
581	41.14	1.88	.10	5.15	643	37.17	2.45		2.24
582	26.20	4.08	.76	34.16	644	30.54	6.28		2.19
583	38.64	4.56	.97	Trace.	646	17.10	3.29		14.36
584	27.06	24.42	.04	41.45	647	9.50	1.30		4.96
585	12.77	4.79	.42	6.98	648	28.19	3.46		9.28
586	3.21	1.71	.32	6.57	649	21.39	1.78		4.50
587	33.33	1.73	.12	17.36	653	22.30	1.90		Trace.
588	3.06	0	.10	Trace.	654	31.70	.80		Trace.
589	2.37	0.46	.08	Trace.	659	26.17	2.72		
590	2.10	.74	.21	3.79	664	21.62	2.10		4.18
591	27.86	1.06	0	28.17	673	32.75	6.08		14.47
592	42.23	21.08	0	3.80	750	27.68	2.92		

The samples from Mona Island represent materials from different caves, but by no means represent all the deposits on the island.

VEGETATION TESTS WITH BAT GUANOS.

GENERAL METHOD OF CONDUCTING TESTS.

Many vegetation experiments in pots were conducted to compare the fertilizing efficiency of the nitrogen or phosphoric acid in bat guanos with the efficiency of the nitrogen or phosphoric acid in standard commercial fertilizers. The results from some 2,300 pots are

included in this work. The general plan of these tests varied somewhat from the usual plans, embodying, it is believed, some improvements. A complete description of the plan and its advantages has been published in another place.[1]

In brief, the plan was to compare the efficiency of the fertilizing element in the guano with the efficiency of the element in a standard fertilizer, on the basis of the relative amounts of the elements from the two sources required to produce the same increased yields. In testing the efficiency of the phosphoric acid, for instance, a series of pots received increasing amounts of acid phosphate, while other pots received phosphoric acid from different guanos. From the weights of the crops grown in the acid-phosphate series a curve was plotted showing the amount of phosphoric acid from acid phosphate required to produce any increased yield in that particular test. From the curve the amount of phosphoric acid from acid phosphate could be found which would have been required to produce the same yield as that produced by any one of the guanos. The ratio of these two quantities of phosphoric acid (from the guano and acid phosphate) which produced the same increased yield gave the efficiency of the phosphoric acid in the guano relative to that of acid phosphate.

The efficiency of the citrate-soluble phosphoric acid in acid phosphate in all the following tests was taken as 100 and the other efficiencies expressed relative to this. Thus, if 2 grams of phosphoric acid from a guano gave the same yield as 1 gram of phosphoric acid from acid phosphate, the efficiency of the guano phosphoric acid was taken as 50.

Glazed earthenware pots were used as containers. They were kept on trucks in a wire inclosure (five meshes to the inch) during fair weather, but run into a glass house during rains and violent winds.

The water content of the soil was kept constant by daily weighings, transpired or evaporated water being replaced by rain water caught on the glass roof of the plant house. When the plants had attained considerable size the weights of the pots plus soil were corrected for the added weight of the plants. Plants grown under these conditions were equal in size to field plants where the maximum fertilizer was used.

Both green and oven-dry weights of the crops from each pot were determined, although in most cases it made little difference whether efficiencies were calculated from green or dry weights. For the sake of conciseness, only oven-dry weights are reported, except in two tests (Tables VIII and XX). Determinations of nitrogen or phosphoric acid in the crop were not so essential with the plan employed as with the usual method, as has been pointed out.[2]

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[1] Gile, P. L., and Carrero, J. O. A plan for testing efficiencies of fertilizers. Jour. Amer. Soc. Agron., 8 (1916), No. 4, pp. 247-255, fig. 1.

[2] Gile, P. L., and Carrero, J. O. Loc. cit.

Corn (*Zea mays*), millet (*Setaria italica*), and rice (*Oryza sativa*) were the crops used. Millet and rice were grown to maturity, and transplanted corn seedlings were grown 30 to 40 days.

The fertilizing materials were mixed with the first 3 or 4 inches of soil in each pot before planting. When a second application of the basic fertilizer was used, it was applied to the surface in dilute solution.

EXPERIMENTS ON EFFICIENCY OF PHOSPHORIC ACID IN BAT GUANOS.

Plan of experiments and materials used.—In testing the efficiencies of the different guanos as phosphatic fertilizers it was necessary to conduct the work in considerable detail on account of the many factors affecting the availabilities of phosphatic fertilizers. The relative efficiencies of different phosphates are known to vary somewhat with the kind of soil and crop, and to be differently affected by liming. There is also supposed to be a difference between the efficiencies of phosphates applied immediately to the crop and those applied sometime before the crop is planted. Certain representative samples of guano were tested with respect to these variable conditions of soil, crops, liming, and effect of remaining in the soil. Most of the samples, however, were tested only for their immediate availability or efficiency in one soil, the river sand.

In the following tests two soils deficient in phosphoric acid were used, a river sand [1] and the Porto Rican red clay.[2] The red clay, fully described elsewhere, is acid and consists almost entirely of silt and clay particles. The river sand is neutral in reaction and contains considerable coarse and medium sand and a small amount of clay particles. It is doubtless derived from clay soil as the river which deposits it drains a red clay area.

The guanos were all compared with acid phosphate as a standard, but bone meal, basic slag, finely ground rock phosphate or floats, and a leached bird guano from Mona Island were also used in many tests to afford a better idea of the position of bat guanos among phosphatic fertilizers in general. Analyses of these materials are given in Table VII.

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[1] Porto Rico Sta. Bul. 11 (1911), p. 22.

[2] Porto Rico Sta. Bul. 14 (1914).

TABLE VII.—*Analyses of phosphatic materials used in vegetation tests with bat guanos.*

Laboratory number.	Material.	Total phosphoric acid (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.
		Per cent.	*Per cent.*	*Per cent.*
720	Basic slag	17.90	....	[a] 9.57
730	Acid phosphate	21.33	14.98	17.27
750	Mona guano [b]	27.68	....	2.92
771	Bone meal	26.03	....	....
822	Floats	30.63	....	.73

[a] Fourteen per cent available by solubility in 2 per cent citric acid.
[b] Sample from a mixed lot of guano from Mona Island.

A basic fertilization with nitrogen and high-grade potash salts was given to all pots, the quantity being shown under the detailed results of the tests. One-half the nitrogen applied was derived from nitrate of soda and the other half from sulphate or chlorid of ammonia. The nitrogen was divided between nitrate and ammonia as previous work had shown that insoluble phosphates are more available with sulphate of ammonia than with nitrate of soda, doubtless because the sulphate leaves an acid residue in the soil, the nitrate an alkaline.[1] With the nitrogen divided between the two forms the results are of more general applicability.

Immediate efficiency of the phosphoric acid in sandy soil.—In these tests, the phosphates were mixed with the soil one or two days before planting with corn or millet. The results, therefore, show the immediate availability of the phosphates for short-time crops. River sand No. 213, with a water content of 18 per cent in the dry soil, was used in all cases. Detailed results are given in the following table. Where a sample has a letter in addition to its number, as No. 263A, this signifies that 263A is a subsample drawn from the same lot from which No. 263 was drawn.

[1] Prianishnikov, D. N., Ber. Deut. Bot. Gesell., 23 (1905), No. 1, pp. 8–17. Söderbaum, H. G., Landw. Vers. Stat., 63 (1905), No. 3–4, pp. 247–262.

TABLE VIII.—*Immediate availability of phosphoric acid in guanos.*

CORN GROWN SEPT. 9 TO OCT. 10, 1914.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Basic fertilizer applied per pot.	Dry soil per pot.	Number of plants per pot.	Green yield of individual pots.							Average green yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate=100.
	Grams.		*Pounds.*		*Grams.*	*Grams.*	*Grams.*	*Grams*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
No phosphate	....	Sodium nitrate, 8.4 gm.; ammonium sulphate, 6 gm.; potassium sulphate, 8 gm.; in three applications.	41	4	234	279	152	239	....	....	....	226±18	....
Acid phosphate	0.30				344	369	370	350	....	....	....	358± 4	....
Do	.60				534	484	456	494	....	....	....	492±11	....
Do	.90				642	565	541	522	....	....	....	568±18	....
Do	1.35				656	639	756	674	....	....	....	681±17	....
Do	2.03				639	669	724	670	....	....	....	676±12	....
Guano No. 263	2.40				538	536	578	497	....	....	....	537±11	29
Guano No. 375	2.40				460	538	482	461	....	....	....	460± 5	22
Guano No. 497	2.10				334	309	373	375	....	....	....	348±11	13
Guano No. 500	2.40				569	533	601	526	....	....	....	557±12	36
Guano No. 502	1.50				314	257	266	290	....	....	....	282± 9	9
Guano No. 504	3.60				280	215	259	256	....	....	....	252± 9	2
Guano No. 506	3.60				341	292	299	330	....	....	....	316± 8	6
Guano No. 509	3.60				328	284	316	271	....	....	....	300± 9	5

TABLE VIII.—*Immediate availability of phosphoric acid in guanos*—Continued.

CORN GROWN OCT. 30 TO DEC. 5, 1914.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Basic fertilizer applied per pot.	Dry soil per pot.	Number of plants per pot.	Oven-dry yield of individual pots.							Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate=100.
	Grams.		*Pounds.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
No phosphate	...	Sodium nitrate, 8.4 gm.; ammonium sulphate, 6 gm.; potassium sulphate, 8 gm.; in two applications.	46	4	10.2	8.3	9.0	9.9	10.4	...	...	9.6±0.3	...
Acid phosphate	0.30				15.9	23.1	13.6	17.4	19.6	...	...	17.9±1.1	...
Do	.60				30.8	31.2	26.7	19.6	...	...	...	27.1±1.8	...
Do	.90				36.9	48.0	36.7	40.5	...	...	...	40.5±1.8	...
Do	1.35				64.4	60.9	66.1	54.0	...	...	...	61.4±1.8	...
Do	2.03				76.5	82.6	77.4	84.6	...	...	...	80.3±1.3	...
Guano No. 498	1.80				23.7	25.4	22.2	24.3	...	...	...	23.9± .4	28
Guano No. 499	1.80				19.7	22.3	22.0	24.3	...	...	...	22.1± .6	24
Guano No. 501	3.60				38.7	29.8	31.8	21.4	...	...	...	30.4±2.4	19
Guano No. 503	1.20				30.4	41.9	28.6	39.6	...	...	...	35.1±2.2	65
Guano No. 505	3.60				12.7	14.0	10.8	15.5	...	...	...	13.3± .8	4
Guano No. 507	1.80				26.9	30.4	19.4	25.5	...	...	...	25.6±1.5	31
Guano No. 508	3.60				12.2	11.4	10.9	11.5	...	...	...	11.5± .2	2
Do	14.40				17.0	14.1	10.6	14.3	...	...	...	14.0± .9	1
Guano No. 472	.80				35.1	38.0	26.1	36.0	...	...	...	33.8±1.8	94
Guano No. 733	1.20				40.7	33.7	33.9	38.9	...	...	...	36.8±1.1	68
Guano No. 750	1.20				13.7	11.8	14.1	...	...	...	...	13.2± .5	11

CORN GROWN NOV. 23 TO DEC. 31, 1914.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Basic fertilizer applied per pot.	Dry soil per pot.	Number of plants per pot.	Oven-dry yield of individual pots.							Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate=100.
No phosphate	...	Sodium nitrate, 8.4 gm.; ammonium sulphate 6 gm.; potassium sulphate, 8 gm.; in three applications.	46	4	9.1	6.8	9.0	8.4	8.2	9.2	8.5	8.5±0.2	...
Acid phosphate	0.30				19.1	15.9	22.2	14.7	14.1	...	...	17.2±1.0	...
Do	.60				22.2	31.0	27.1	33.7	22.2	...	...	27.2±1.5	...
Do	.90				33.7	43.5	54.0	44.3	48.3	...	...	44.8±2.2	...
Do	1.35				45.8	60.1	49.1	66.4	70.6	...	...	58.4±3.2	...
Do	2.03				66.9	82.9	88.9	99.7	86.1	...	...	84.9±3.6	...
Guano No. 734	1.20				21.1	22.4	23.9	24.0	...	...	...	22.9± .5	39
Do	1.80				24.4	32.1	35.0	29.4	...	...	...	30.2±1.5	36
Do	2.70				51.3	41.8	51.9	52.0	...	...	...	49.3±1.7	39
Do	4.05				65.9	71.2	87.1	78.5	...	...	...	75.7±3.0	45
Guano No. 509	3.60				9.9	10.4	9.6	12.6	...	...	...	10.6± .5	2
Do	7.20				13.8	18.1	16.2	13.1	...	...	...	15.3± .8	3
Do	14.40				20.4	14.5	25.5	18.1	...	...	...	19.6±1.5	3

Do	28.80				31.7	29.3	29.1	25.5	....	....	....	28.9± .9	2
Guano No. 321	2.40				26.5	24.2	33.4	38.1	....	....	....	30.6±2.1	27
Guano No. 374	2.40				31.0	27.0	34.7	35.8	....	....	....	32.1±1.3	28
Guano No. 415	3.60				42.3	32.8	56.6	39.5	....	....	....	42.8±3.4	24
Guano No. 447	1.80				19.8	23.5	27.5	19.5	....	....	....	22.6±1.3	26
Guano No. 458	1.80				34.5	32.0	40.4	31.2	....	....	....	34.5±1.4	40
Guano No. 460	1.80				17.7	13.2	15.9	15.3	....	....	....	15.5± .6	14
Guano No. 376	1.20				25.2	25.8	23.0	22.0	....	....	....	24.0± .6	42
Guano No. 750	2.40				13.4	13.4	15.4	19.7	....	....	....	15.5±1.0	10
CORN GROWN FEB. 16 TO MAR. 29, 1915.													
No phosphate	....	Sodium nitrate, 8.4 gm.; ammonium chlorid, 5.3 gm.; potassium sulphate, 8 gm.; in two applications.	47	4	10.2	7.9	11.9	7.6	10.0	....	....	9.5±0.5	....
Acid phosphate	0.30				18.6	19.6	19.0	16.1	22.8	....	....	19.2± .7	....
Do	.60				32.2	39.4	38.0	32.9	35.1	....	....	35.5± .9	....
Do	.90				56.4	50.4	54.6	44.2	53.8	....	....	51.9±1.5	....
Do	1.35				73.0	74.6	82.6	69.2	73.5	....	....	74.6±1.5	....
Do	2.03				89.6	96.9	105.9	90.9	99.0	....	....	96.5±2.0	....
Guano No. 498	3.00				42.0	41.2	58.7	35.6	50.4	....	....	45.6±2.7	26
Guano No. 499	3.00				38.4	48.3	42.9	52.0	43.8	....	....	45.1±1.6	26
Guano No. 506	8.00				35.6	22.3	26.4	21.9	....	....	....	26.5±2.1	5
Basic slag	1.30				51.0	57.6	62.5	59.5	51.7	....	....	56.5±1.5	76
Bone meal	1.40				31.1	42.3	30.7	37.7	36.3	....	....	35.6±1.5	43
MILLET GROWN MAR. 12 TO APR. 21, 1915.													
No phosphate	....	Sodium nitrate, 2.8 gm.; ammonium chlorid, 1.8 gm.; potassium sulphate, 2.7 gm.; in two applications.	18	8	1.9	1.5	2.0	2.1	1.7	....	....	1.8±0.1	....
Acid phosphate	.07				3.7	3.6	2.7	2.6	3.9	....	....	3.3± .2	....
Do	.14				4.7	4.1	4.2	3.4	5.6	....	....	4.4± .3	....
Do	.21				6.0	6.5	8.3	4.6	9.4	....	....	7.0± .6	....
Do	.32				12.2	9.3	9.2	8.4	13.1	....	....	10.4± .6	....
Do	.47				12.3	9.8	13.5	12.7	12.1	....	....	12.1± .4	....
Do	.71				26.6	13.5	20.3	22.4	21.5	....	....	20.9±1.4	....
Basic slag	.50				9.3	9.8	9.1	9.9	13.1	....	....	10.2± .5	62
Bone meal	.54				2.1	3.7	3.4	5.6	4.9	....	....	3.9± .4	20
Guano No. 263	.95				9.0	7.5	7.5	13.2	8.0	....	....	9.0± .7	29
Guano No. 497	1.40				7.7	9.5	9.7	9.7	7.7	....	....	8.9± .3	19
Guano No. 498	.95				8.1	6.2	6.4	7.2	8.6	....	....	7.3± .3	23
Guano No. 499A	1.07				8.6	5.5	8.5	8.2	7.6	....	....	7.7± .4	22
Guano No. 500A	.94				8.2	7.1	9.1	11.1	5.5	....	....	8.2± .6	26
Guano No. 501	1.50				7.7	8.0	7.2	11.3	7.5	....	....	8.3± .5	17
Guano No. 502	2.50				5.8	7.1	7.8	8.7	7.0	....	....	7.3± .3	9
Guano No. 503	.50				10.8	10.6	7.9	6.5	7.1	....	....	8.6± .6	53
Guano No. 750	2.50				4.6	5.2	4.4	4.5	5.5	....	....	4.8± .1	6

TABLE VIII.—*Immediate availability of phosphoric acid in guanos*—Continued.

CORN GROWN APR. 12 TO MAY 17, 1915.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Basic fertilizer applied per pot.	Dry soil per pot.	Number of plants per pot.	Oven-dry yield of individual pots.							Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate=100.
	Grams.		*Pounds.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
No phosphate	....	Sodium nitrate, 8.4 gm.; ammonium chlorid, 5.3 gm.; potassium sulphate, 8 gm.; in two applications.	47	4	10.3	7.2	6.7	13.0	7.2	....	....	8.9±0.8	....
Acid phosphate	0.30				15.1	13.8	17.8	16.0	19.4	....	....	16.4± .7	....
Do	.60				49.5	29.2	30.6	25.8	32.0	....	....	33.4±2.8	....
Do	.90				51.2	39.0	50.5	45.3	52.1	....	....	47.6±1.6	....
Do	1.35				64.9	59.6	63.8	64.3	58.1	....	....	62.1± .9	....
Do	2.03				75.3	84.8	86.1	78.7	78.1	....	....	80.6±1.4	....
Guano No. 263A	2.67				51.3	65.6	47.4	46.4	45.4	....	....	51.2±2.5	38
Guano No. 501	4.00				25.4	29.7	25.1	34.5	45.0	....	....	31.9±2.5	15
Guano No. 780	1.00				42.3	37.7	46.3	37.8	40.8	....	....	41.0±1.1	76
Guano No. 784	1.60				23.9	40.9	26.7	30.3	34.7	....	....	31.3±2.0	35
Guano No. 785	1.60				31.8	28.9	37.1	36.8	38.1	....	....	34.5±1.2	39
Guano No. 796	6.00				8.4	10.0	11.2	10.7	12.8	....	....	10.6± .5	1
Guano No. 797	2.00				17.0	19.0	17.5	27.2	17.6	....	....	19.7±1.3	18
Guano No. 798	4.80				13.3	10.3	16.2	13.9	12.9	....	....	13.3± .6	4
Guano No. 810	4.80				15.9	25.1	16.8	20.2	20.0	....	....	19.6±1.1	8
Guano No. 811	2.40				20.7	13.7	10.7	23.0	23.5	....	....	18.3±1.8	14
Guano No. 819	1.00				32.2	32.0	36.5	40.7	39.1	....	....	36.1±1.2	66
Floats	6.00				18.8	22.6	19.9	25.3	33.8	....	....	24.1±2.7	7
Do	18.00				38.0	35.7	32.3	28.4	39.4	....	....	34.8±1.3	4
Guano No. 793	2.40				41.9	43.5	37.4	57.2	43.0	....	....	44.6±2.3	35

MILLET GROWN APR. 30 TO JUNE 15, 1915.

No phosphate	......	Sodium nitrate, 8.4 gm.; ammonium chlorid, 5.3 gm.; potassium sulphate, 8 gm.; in two applications.	47	27	23.0	17.8	20.3	15.6	......	......	......	19.2±1.1	......
Acid phosphate	0.30				33.2	30.0	23.5	29.0	......	......	......	28.9±1.3	......
Do	.60				40.8	51.2	47.1	39.0	......	......	......	44.5±1.9	......
Do	.90				69.2	54.8	64.6	52.9	......	......	......	60.4±2.6	......
Do	1.35				68.1	84.4	67.9	71.7	......	......	......	73.0±2.6	......
Do	2.03				88.9	85.4	90.1	90.6	......	......	......	88.8± .8	......
Do	3.05				88.4	106.8	93.5	88.3	......	......	......	94.3±2.9	......
Guano No. 472A	1.02				65.2	64.6	66.0	60.4	......	......	......	64.1± .8	101
Guano No. 504	8.00				16.5	21.3	17.6	23.5	......	......	......	19.7±1.1	0
Guano No. 505A	9.69				33.3	25.6	31.0	38.1	......	......	......	32.0±1.7	4
Guano No. 506	4.00				31.1	42.3	43.1	36.9	......	......	......	38.4±1.9	12
Guano No. 507	2.70				46.3	49.7	50.2	49.5	......	......	......	48.9± .6	25
Guano No. 508	8.00				14.2	36.5	19.5	22.9	......	......	......	23.3±3.2	2
Guano No. 509	8.00				27.8	24.2	30.3	34.8	......	......	......	29.3±1.5	4
Guano No. 733	1.20				50.6	44.1	53.8	54.9	......	......	......	50.9±1.6	60
Guano No. 734	2.00				51.1	41.8	52.6	52.7	......	......	......	49.6±1.7	35
Guano No. 780	1.00				52.3	54.1	50.6	57.2	......	......	......	53.6± .9	77
Guano No. 785	1.60				52.7	42.3	42.6	44.5	......	......	......	45.5±1.6	38
Guano No. 797	2.00				32.4	34.5	33.8	37.3	......	......	......	34.5± .7	20
Guano No. 799	2.70				54.2	55.2	59.6	55.3	......	......	......	56.1± .8	31
Guano No. 810	4.00				41.8	34.2	30.6	39.6	......	......	......	36.6±1.7	11
Guano No. 811	2.40				29.5	26.5	40.8	32.5	......	......	......	32.3±2.1	15
Guano No. 818	3.20				40.0	58.8	54.1	48.5	......	......	......	50.4±2.7	22
Guano No. 819	1.00				52.2	43.9	43.4	46.8	......	......	......	46.6±1.3	65
Floats	8.00				21.3	31.8	24.6	34.8	......	......	......	28.1±2.1	4

MILLET GROWN MAY 31 TO JULY 16, 1915.

No phosphate	......	Sodium nitrate, 2.8 gm.; ammonium chlorid, 1.8 gm.; potassium sulphate, 2.7 gm.; in two applications.	13	12	7.1	10.5	6.3	10.3	8.6	8.1	......	8.5±0.5	......
Acid phosphate	0.10				14.0	14.9	10.4	11.3	12.3	16.7	......	13.3± .6	......
Do	.20				15.4	16.1	17.2	15.7	16.5	16.1	......	16.2± .2	......
Do	.30				17.6	16.8	19.1	18.6	19.1	18.0	......	18.2± .3	......
Do	.45				23.4	19.0	22.8	19.9	23.4	25.3	......	22.3± .7	......
Do	.675				26.0	23.1	25.0	22.3	29.6	26.2	......	25.4± .7	......
Guano No. 751	.50				22.7	25.3	19.2	23.7	24.4	20.2	......	22.6± .7	104
Guano No. 790	2.80				13.7	13.0	14.0	12.9	13.1	15.2	......	13.7± .2	4
Guano No. 806	1.40				15.5	13.2	16.4	15.7	15.8	14.4	......	15.2± .2	12
Guano No. 807	2.40				13.7	13.2	18.2	14.3	13.5	12.7	......	14.3± .6	6
Guano No. 816	1.70				18.7	18.2	18.4	17.5	17.6	19.3	......	18.3± .2	18
Guano No. 824	3.60				14.7	10.0	12.0	12.4	13.7	11.7	......	12.4± .5	2
Guano No. 841	1.40				16.0	14.4	16.0	16.1	17.9	16.3	......	16.1± .3	14
Guano No. 842	.80				13.8	12.7	11.5	15.7	11.9	13.5	......	13.2± .4	12
Guano No. 846	.80				10.5	15.1	9.8	11.7	12.5	11.7	......	11.9± .5	9

TABLE VIII.—*Immediate availability of phosphoric acid in guanos*—Continued.

MILLET GROWN OCT. 15 TO NOV. 22, 1915.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Basic fertilizer applied per pot.	Dry soil per pot.	Number of plants per pot.	Oven-dry yield of individual pots.							Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate=100.
	Grams.		*Pounds.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
No phosphate	....				6.6	4.4	6.5	6.1	7.4	6.0	6.7	6.2±0.2	....
Acid phosphate	0.15				10.0	10.8	10.7	10.8	10.5	10.0	11.1	10.6± .1	....
Do	.30				15.6	16.1	15.7	15.5	17.2	16.8	18.1	16.4± .2	....
Do	.45				21.0	19.4	20.9	21.1	20.9	21.0	19.8	20.6± .2	....
Do	.675				24.6	21.5	23.4	23.4	25.5	24.5	23.8	23.8± .3	....
Guano No. 846	2.50	Sodium nitrate, 2.8 gm.; ammonium sulphate, 2 gm.; potasium sulphate, 2.7 gm.; in two applications.	16	14	13.4	15.1	15.1	15.9	16.2	12.5	14.2	14.6± .3	10
Guano No. 852	.50				15.2	15.8	19.5	17.1	16.6	13.6	16.0	16.3± .5	60
Guano No. 853	2.50				25.0	24.4	25.5	24.7	23.1	25.1	27.1	25.0± .3	27+
Guano No. 912	3.00				7.9	6.6	7.8	7.4	6.6	7.9	7.0	7.3± .2	1
Guano No. 916	3.00				7.3	7.1	6.3	7.2	7.3	8.1	7.5	7.3± .1	1
Guano No. 931	1.35				18.2	19.3	19.4	20.0	19.2	20.2	20.7	19.6± .2	31
Guano No. 932	1.50				14.8	17.0	15.8	15.8	16.0	14.7	16.5	15.8± .2	19

MILLET GROWN DEC. 8, 1915, TO JAN. 22, 1916.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Basic fertilizer applied per pot.	Dry soil per pot.	Number of plants per pot.	Oven-dry yield of individual pots.							Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate=100.
No phosphate	....				7.7	7.8	7.7	8.1	9.1	8.5	....	8.2±0.2	....
Acid phosphate	0.15				11.6	11.0	10.2	11.1	10.7	13.0	....	11.3± .3	....
Do	.30				14.0	14.5	14.0	15.1	16.1	16.0	....	15.0± .3	....
Do	.45				18.1	18.6	16.0	17.3	18.0	18.2	....	17.7± .3	....
Do	.675				21.1	21.4	20.5	22.5	22.6	22.2	....	21.7± .2	....
Guano No. 851	1.40				12.9	14.4	10.5	12.2	15.2	13.4	....	13.1± .5	15
Guano No. 881	.60				14.2	20.5	15.6	15.6	15.3	18.2	....	16.6± .6	65
Guano No. 955	2.50	Sodium nitrate, 2.1 gm.; ammonium sulphate, 1.5 gm.; potassium sulphate, 2 gm.; in one application.	17.5	13	11.2	9.8	10.2	10.1	7.2	7.1	....	9.3± .4	2
Guano No. 959	.70				13.9	13.7	12.6	13.4	13.4	13.1	....	13.4± .1	33
Guano No. 961	.50				13.6	12.4	15.5	12.8	14.0	12.9	....	13.5± .3	49
Guano No. 975	2.40				9.0	11.3	10.7	9.4	....	9.6	....	10.0± .3	4
Guano No. 977	.50				18.6	22.0	18.0	18.1	18.3	20.7	....	19.3± .7	108
Guano No. 978	.55				18.8	18.9	18.3	19.5	16.5	17.3	....	18.2± .3	87
Guano No. 980	2.40				10.9	9.5	10.6	....	11.4	10.1	....	10.5± .2	5
Guano No. 985	.65				12.0	12.6	13.4	12.9	12.2	....	....	12.6± .2	31

MILLET GROWN MAR. 20 TO MAY 2, 1916.

No phosphate	....	Sodium nitrate, 2.8 gm.; ammonium chlorid, 1.8 gm.; potassium sulphate, 2.7 gm.; in two applications.	14.5	14	6.7	6.4	8.6	6.5	6.1	8.0	6.8	7.0±0.2	....
Acid phosphate	0.15				11.6	10.9	9.7	13.4	11.9	12.6	....	11.7± .4	....
Do	.30				18.1	15.8	17.6	19.1	18.0	17.2	....	17.6± .3	....
Do	.45				22.9	24.6	19.2	22.3	20.4	22.3	....	22.0± .5	....
Do	.675				26.0	28.0	28.3	27.5	26.9	29.1	....	27.6± .4	....
Guano No. 939	1.60				17.1	19.4	16.7	16.1	17.4	20.9	....	17.9± .5	20
Guano No. 943	3.00				13.1	17.1	16.7	18.1	17.4	20.4	....	17.1± .7	10
Guano No. 945	.90				21.6	24.3	22.6	22.1	19.5	22.2	....	22.1± .4	51
Guano No. 947	2.50				17.0	13.7	14.9	17.1	13.6	15.8	....	15.4± .4	10
Guano No. 965	.60				12.1	9.9	10.3	10.9	8.9	10.4	....	10.4± .3	18
Guano No. 970	.90				15.4	14.2	13.8	14.0	15.0	15.5	....	14.7± .2	25
Guano No. 971	.90				16.2	17.9	18.1	16.8	16.8	17.0	....	17.1± .2	32
Guano No. 1011	1.20				10.8	11.5	11.3	11.1	11.9	9.8	....	11.1± .2	11
Guano No. 1013	3.00				9.2	7.7	7.8	8.8	8.4	9.4	....	8.6± .2	2
Guano No. 1018	3.00				9.0	9.9	9.1	8.0	8.7	9.6	....	9.1± .2	2

The efficiencies of the phosphates as found by vegetation tests are expressed relative to that of acid phosphate taken as 100. Thus, if the percentage of total phosphoric acid in a guano be multiplied by its efficiency value and divided by 100, the result will be the percentage of phosphoric acid in the guano which is as available as that in acid phosphate. For example, No. 321, containing 14.47 per cent total phosphoric acid with an efficiency of 27, contains 3.91 per cent of phosphoric acid which is as available as that in acid phosphate, $\frac{14.47 \text{ per cent} \times 27}{100} = 3.91$ per cent.

It will be noted that certain guanos were tested several times. Some of these duplications were made to gain an idea of the accuracy of the work, others are due to the same guano's being used in several tests of the effect of different conditions on efficiencies.[1]

The efficiency of the phosphoric acid in the different samples tested varied between 0 and 108. In respect to availability in a sandy soil, some of the guanos are, therefore, as good as the best fertilizers carrying phosphoric acid, while others are practically worthless. In about half the samples tested, the phosphoric acid had an efficiency of 20 or more, which compares well with bone meal under the same conditions. While a large part of the guanos must be considered as phosphatic fertilizers of low availability, nearly all were more effective than finely ground phosphate rock or floats.

Six samples of fresh or only slightly decomposed bat manure were tested, Nos. 472, 503, 751, 780, 881, and 977. The phosphoric acid was of high efficiency in all, ranging from 59 to 108, the average being 84. In respect to efficiency (not quantity) of its phosphoric acid, the fresh bat manure, therefore, ranks with the best phosphatic fertilizers.

Efficiency of the phosphoric acid as affected by the crop.—As different crops are supposed to vary in their ability to utilize the slightly soluble phosphates, the relative efficiency of different phosphates depends somewhat on the crop used as a test. In some cases different efficiencies of phosphates for different crops are due to distinct secondary effects of the phosphates, as acidity or basicity.[2] This, however, is really a question of the interaction between soil and phosphate rather than between crop and phosphate.

When a quick-growing crop requires considerable phosphoric acid, one phosphate may be more effective than another because it is more

[1] Determinations of efficiency of the same material repeated in different tests agree very closely for the most part. In some cases lack of agreement was partially due to experimental errors. Differences due to experimental errors, however, were probably small in most cases, as duplicate determinations made in the same test agreed very closely. The larger variations, such as occurred with bone meal, were doubtless due to real differences in the efficiencies of the materials in the different lots of soil. While the same type of soil was used in all the tests reported in Table VIII, different lots were secured for different experiments, and these lots of course varied somewhat in character.

[2] The good effect of basic slag on clover has often been noted.

soluble, that is, it supplies soluble phosphoric acid at a faster rate. Without attempting a detailed discussion of a subject which still needs investigation, it may be pointed out that, whether or not different crops have different powers of "feeding" on insoluble phosphates, it is well established that one phosphate may be much more effective than another for a certain crop.

Table IX has been compiled from the figures in Tables VIII and X to XV.

TABLE IX.—*Effect of crop on the availability of phosphoric acid in guanos.*

Source of phosphoric acid (P_2O_5).	Crop.	Efficiency of phosphoric acid compared with that of acid phosphate=100.	Source of phosphoric acid (P_2O_5).	Crop.	Efficiency of phosphoric acid compared with that of acid phosphate=100.
Guano No. 263	Millet	29	Guano No. 733	Millet	60
	Corn	29		Corn	68
Guano No. 497	Millet	19	Guano No. 750	Millet	6
	Corn	13		Corn	a 11
Guano No. 498	Millet	23	Guano No. 780	Millet	77
	Corn	a 27		Corn	76
Guano No. 501	Millet	17	Guano No. 785	Millet	38
	Corn	a 17		Corn	39
Guano No. 502	Millet	9	Guano No. 797	Millet	20
	Corn	9		Corn	18
Guano No. 503	Millet	53	Guano No. 810	Millet	11
	Corn	a 75		Corn	8
Guano No. 504	Millet	0	Guano No. 811	Millet	15
	Corn	a 1		Corn	14
Guano No. 506	Millet	12	Guano No. 819	Millet	65
	Corn	a 5		Corn	66
Guano No. 507	Millet	25	Floats	Millet	a 4
	Corn	a 30		Corn	a 6
Guano No. 508	Millet	2	Slag	Millet	a 65
	Corn	a 2		Corn	76
Guano No. 509	Millet	4	Bone meal	Millet	a 29
	Corn	a 3		Corn	43

a Average from several determinations.

In the above table comparisons are given of the efficiencies of bone meal, slag, floats, and 19 different guanos for corn and millet. In 50 per cent of the cases the difference between the efficiencies for corn and millet was 3 or less, the average for the efficiencies of the 22 samples being 27 for millet and 29 for corn. It is therefore apparent that the guanos are equally effective for corn and millet.

The effectiveness of guanos for rice was also tried, but as the growth of rice was increased only 20 per cent by abundant phosphoric acid, few efficiencies could be calculated. Guanos Nos. 502, 505, 506, and 508 showed no availability for rice in this test. In this same lot of soil, the growth of corn was increased 300 per cent by phosphatic fertilization and the same guanos which had no availability for rice had a very low availability or none for corn. This test demonstrates how much less rice responds to phosphatic fertilization than corn and shows no greater ability in rice to utilize insoluble phosphates than in corn or millet.

Efficiency of the phosphoric acid as affected by the kind of soil.—To gain some idea of the extent to which the efficiencies of the guanos might vary with the character of the soil, acid phosphate was compared with bone meal, slag, floats, and 12 guanos in the red clay soil and river sand.

Table X gives the results of a comparative test of 8 of the guanos in the two soils. In this test 25 millet plants per pot were grown, the experiment running from December 30, 1915, to February 17, 1916, with a basic fertilizer consisting of 8.4 grams sodium nitrate, 6 grams ammonium sulphate, and 8 grams potassium sulphate per pot given in two applications.

TABLE X.—*Effect of soil on immediate availability of phosphoric acid in guanos.*

RIVER SAND NO. 213 (46 LBS. DRY SOIL PER POT, WATER CONTENT 18 PER CENT.)

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Oven-dry yield of individual pots.					Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate=100.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
No phosphate	....	11.6	12.5	8.2	12.9	13.3	11.7±0.8	....
Acid phosphate	0.40	26.9	26.9	25.1	27.0	....	26.5± .3	....
Do	.80	34.3	42.7	35.6	39.5	....	38.0±1.2	....
Do	1.28	53.8	46.9	46.3	47.9	....	48.7±1.2	....
Do	1.92	57.2	56.5	57.9	60.5	....	58.0± .6	....
Basic slag	1.60	46.5	48.1	47.8	42.7	....	46.3± .8	73
Bone meal	3.00	36.5	37.3	36.0	34.8	....	36.2± .4	25
Floats	8.00	26.7	21.3	18.2	18.2	....	21.1±1.3	3
Guano No. 917	2.00	12.1	12.0	14.0	18.6	....	14.2±1.0	3
Guano No. 928	3.50	28.8	30.4	28.0	30.0	....	29.3± .4	14
Guano No. 936	3.50	47.5	47.7	44.0	52.7	....	48.0±1.2	36
Guano No. 957	2.50	41.1	41.6	39.6	43.2	....	41.4± .5	38
Guano No. 966A	3.00	31.0	31.0	32.0	35.5	....	32.4± .7	20
Guano No. 977	1.30	43.5	44.2	40.2	46.3	....	43.6± .8	81
Guano No. 981	6.00	19.5	17.8	17.2	19.8	....	18.6± .4	3
Guano No. 982	1.60	30.9	29.4	30.1	30.7	....	30.3± .2	33

RED CLAY (41 LBS. DRY SOIL PER POT, WATER CONTENT 35 PER CENT).

No phosphate	....	12.2	16.2	14.4	15.8	17.7	15.3±0.6	....
Acid phosphate	.40	42.7	42.0	43.5	34.6	....	40.7±1.4	....
Do	.80	53.5	47.8	45.7	55.1	....	50.5±1.5	....
Do	1.28	67.8	55.9	62.4	59.6	....	61.4±1.7	....
Do	1.92	71.9	73.6	65.9	77.8	....	72.3±1.6	....
Basic slag	1.60	60.9	55.6	61.2	60.2	....	59.5± .8	75
Bone meal	3.00	57.5	66.5	71.9	60.6	....	64.1±2.1	48
Floats	8.00	54.8	65.5	72.5	59.0	....	63.0±2.6	17
Guano No. 917	2.00	9.3	15.7	14.9	22.1	....	15.5±1.7	0
Guano No. 928	3.50	55.7	53.3	52.7	51.0	....	53.2± .6	26
Guano No. 936	3.50	66.3	62.2	65.5	77.4	....	67.9±2.2	47
Guano No. 957	2.50	46.9	47.8	59.4	44.2	....	49.6±2.2	31
Guano No. 966A	3.00	42.5	43.5	58.9	53.5	....	49.6±2.6	26
Guano No. 977	1.30	65.2	63.0	51.8	54.5	....	58.6±2.2	89
Guano No. 981	6.00	55.8	58.9	64.8	59.5	....	59.8±1.2	20
Guano No. 982	1.60	54.5	60.3	60.4	57.3	....	58.1± .9	65

A summary of all data which show the efficiencies of the different materials as affected by the kind of soil is given in Table XI. The figures given in this table are averages of the efficiencies of the different materials as given in Tables VIII, X, and XIII.

TABLE XI.—*Effect of soil on immediate availability of phosphoric acid in guanos.*

Source of phosphoric acid (P_2O_5).	Efficiency of phosphoric acid in— Red clay soil.	Efficiency of phosphoric acid in— Sandy soil.	Difference between efficiency in clay and in sand.	Difference between efficiency in clay and sand expressed as percentage of efficiency in sand.
				Per cent.
Guano No. 797A	50	5	+45	+ 900
Guano No. 851	48	a 16	+32	+ 200
Guano No. 917	0	3	− 3	− 100
Guano No. 928	26	14	+12	+ 86
Guano No. 936	47	36	+11	+ 31
Guano No. 957	31	a 34	− 3	− 9
Guano No. 966A	26	20	+ 6	+ 30
Guano No. 966B	29	8	+21	+ 263
Guano No. 975	50+	4	+46	+1,150
Guano No. 977	89	a 94	− 5	− 5
Guano No. 981	20	3	+17	+ 567
Guano No. 982	65	33	+32	+ 97
Slag	75	a 68	+ 7	+ 10
Bone meal	[1] 53	a 31	+22	+ 71
Floats	[1] 23	a 4	+19	+ 450

a Average from several determinations.

Guanos Nos. 917, 957, 966A, and 977 were no more or only slightly more, effective in clay than in sand, while all other guanos were far more effective in clay. In some cases guanos of such low availability in the sand as to be practically worthless were highly efficient fertilizers in the clay. Relative to acid phosphate, basic slag had about the same efficiency in clay as in sand, while bone meal and floats were much more efficient in the clay.

It should be considered in judging these results that the efficiencies were measured against acid phosphate, that is, they were relative, not absolute. The increased efficiency of some of the phosphates in the clay soil may therefore be due to a depression in the effectiveness of the acid phosphate, or an increase in the effectiveness of the other phosphate, or a combination of the two changes. Which of these changes occurred does not affect the choice of what phosphate to use on a certain soil although it is important for a knowledge of the reactions of the soil.

Efficiency of the phosphoric acid as affected by remaining in the soil.—Certain phosphates are supposed to become more available through various reactions in the soil. Thus finely-ground rock phosphate is supposed to be more effective after it has remained in the soil for a period than it is when applied immediately to the crop.[1] As nearly all guanos contain most, or a large part, of their phosphoric acid in a form which is not immediately available, it was important

[1] Numerous investigators, including P. Wagner, have not been able to establish this, while others have. Possibly the nature of the soil is the determining factor, although some affirmative conclusions have been based on inadequate data.

to know whether they tend to become more available on remaining in the soil. Tests were accordingly conducted, using acid phosphate, bone meal, floats, and 10 guanos. The effects of these materials added to the soil six weeks before planting were compared with those of the same materials added to the soil immediately before planting. Both red clay soil and river sand were used. Detailed results are given in Tables XII and XIII, and a summary in Table XIV.

For the test described in Table XII, millet was grown in river sand No. 213 (45 pounds dry soil per pot with a water content of 18 per cent), 30 plants per pot being grown from October 12 to November 23, 1915, with a basic fertilizer consisting of 8.4 grams sodium nitrate, 6 grams ammonium sulphate, and 8 grams potassium sulphate per pot given in two applications.

For the test in Table XIII, millet was grown in red clay, 38 pounds dry soil per pot with a moisture content of 33 per cent. The plants, 28 to the pot, were grown from May 10 to June 26, 1916, with an application immediately before planting of a basic fertilizer consisting of 6.3 grams sodium nitrate, 4.5 grams ammonium sulphate, and 6 grams potassium sulphate per pot.

TABLE XII.—*Effect of remaining in the soil on the availability of phosphoric acid in guanos.*

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Phosphates applied to soil 6 weeks before planting.								Phosphates applied to soil immediately before planting.						
		Oven-dry yield of individual pots.					Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate applied at the same time.	Efficiency of phosphoric acid as compared with that of acid phosphate applied immediately before planting.	Oven-dry yield of individual pots.					Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate applied at the same time.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*			*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
No phosphate	....	33.0	33.7	31.4	37.3	27.1	32.5±1.1	....	....	36.0	33.7	33.9	32.2	35.9	34.3±0.5	....
Acid phosphate	0.40	48.1	49.1	48.8	43.5	46.3	47.1± .6	....	....	59.3	62.5	59.9	57.4	61.9	60.2± .6	....
Do	.80	62.5	56.8	65.0	56.9	60.3	60.3±1.1	....	....	74.9	75.7	73.4	75.4	78.2	75.5± .5	....
Do	1.40	76.6	70.4	78.1	76.7	70.7	74.5±1.1	....	....	87.7	87.7	81.9	83.3	81.4	84.4± .9	....
Do	2.10	83.9	77.8	87.1	82.1	77.9	81.8±1.2	....	....	82.8	83.8	87.1	85.6	92.9	86.4±1.2	....
Bone meal	2.10	59.5	60.9	65.3	62.5	60.5	61.7± .7	40	21	69.6	63.9	59.9	61.6	63.0	63.6±1.1	23
Guano No. 797A	2.98	62.4	66.6	62.1	59.5	61.5	62.4± .8	30	15	72.3	75.4	68.3	69.4	74.0	71.9± .9	24
Guano No. 811A	4.12	53.5	56.3	55.7	52.2	55.9	54.7± .5	15	8	65.1	63.1	58.0	54.0	56.1	59.3±1.4	9
Floats	8.00	43.1	46.2	44.5	43.5	46.3	44.7± .5	4	2	49.5	46.7	55.4	48.8	47.9	49.7±1.0	3
Guano No. 842A	1.62	45.9	53.1	55.9	57.4	56.1	53.7±1.4	37	19	64.1	59.2	59.5	52.7	52.5	57.6±1.5	22
Guano No. 860	3.20	71.4	66.3	73.3	70.4	62.9	68.9±1.3	36	20	67.7	69.3	73.7	68.5	61.1	68.1±1.4	19
Guano No. 889	3.20	54.5	50.8	50.4	53.3	51.7	52.1± .5	17	11	62.0	58.9	53.8	53.7	56.2	56.9±1.1	11
Guano No. 923	3.20	43.2	40.5	43.2	40.4	37.8	41.0± .7	7	6	50.1	48.2	45.5	45.7	43.9	46.7± .7	6

TABLE XIII.—*Effect of lime on the availability of phosphoric acid in guanos applied 6 weeks or immediately before planting.*

NO LIME.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Phosphates applied to soil 6 weeks before planting. Oven-dry yield of individual pots.					Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate applied at the same time.	Efficiency of phosphoric acid as compared with that of acid phosphate applied immediately before planting.	Phosphates applied to soil immediately before planting. Oven-dry yield of individual pots.					Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate applied at the same time.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*			*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
No phosphate		13.4	12.8	10.4	11.8	11.4	12.0±0.4			10.1	10.7	12.0	10.3	12.3	11.1±0.3	
Acid phosphate	0.30	34.4	33.5	29.0	26.3	31.7	31.0±1.0			36.1	37.3	33.8	38.4	36.4	36.4± .5	
Do	.60	49.1	49.4	47.7	40.4		46.7±1.3			48.9	44.8	45.4	40.1		44.8±1.2	
Do	1.20	50.6	49.0	54.5	56.5		52.7±1.2			58.3	57.6	57.3	68.3		60.4±1.8	
Do	2.00	66.2	62.8	65.1	51.9		61.5±2.2			60.7	75.6	63.6	78.0		69.5±2.8	
Bone meal	2.00	63.0	66.2	72.0	62.0		65.8±1.5	100+	84	56.7	60.8	57.8	59.6		58.7± .6	57
Floats	5.00	80.9	72.3	79.2	59.8		73.1±3.2	40+	40+	67.2	61.6	58.2	63.7		62.7±1.2	29
Guano No. 797A	3.00	54.8	62.2	64.7	51.2		58.2±2.1	57	37	66.9	65.1	60.6	62.4		63.8± .9	50
Guano No. 851	4.00	76.9	80.7	84.2	67.2		77.3±2.4	50+	50+	71.3	70.1	65.4	66.4		68.3± .9	48
Guano No. 966B	3.00	48.2	53.2	49.3	45.0		48.9±1.1	27	25	56.8	55.9	39.5	54.7		51.7±2.7	29
Guano No. 975	4.00	81.0	75.8	65.4	74.7		74.2±2.2	50+	50+	82.1	79.4	69.3	80.5		77.8±1.9	50+
Guano No. 977	1.20	67.5	49.5	55.6	43.6		54.1±3.4	111	80							

AIR-SLAKED LIME, 20 GRAMS PER POT.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Phosphates applied to soil 6 weeks before planting. Oven-dry yield of individual pots.					Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate applied at the same time.	Efficiency of phosphoric acid as compared with that of acid phosphate applied immediately before planting.	Phosphates applied to soil immediately before planting. Oven-dry yield of individual pots.					Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate applied at the same time.
No phosphate		10.4	8.6	9.6	15.0	9.2	10.6±0.8			8.7	5.9	9.6	9.2	7.2	8.1±0.5	
Acid phosphate	0.30	22.1	16.1	22.8	22.1	22.2	21.1± .8			25.7	20.3	22.1	21.7	26.2	23.2±1.0	
Do	.60	33.1	31.9	32.3	32.7		32.5± .2			45.3	52.5	43.2	44.3		46.3±1.4	
Do	1.20	53.1	63.4	59.5	54.3		57.6±1.6			77.3	73.0	76.8	77.2		76.1± .7	
Do	2.00	83.2	79.9	78.9	84.1		81.5± .8			91.7	87.1	83.5	81.3		85.9±1.5	
Bone meal	2.00	41.5	27.6	43.5	33.5		38.7±2.6	38	25	40.1	58.8	16.1	19.1		33.5±6.7	22
Floats	5.00	20.5	12.7	9.1	24.4		16.7±2.3	3	3	8.7	10.7	9.5	10.4		9.8± .3	1
Guano No. 797A	3.00	59.8	55.9	55.3	55.4		56.6± .7	39	27	71.2	54.8	57.2	57.9		60.3±2.5	30
Guano No. 851	4.00	57.1	37.2	38.4	63.8		49.1±4.5	25	17	48.6	47.3	44.0	41.7		45.4±1.0	15
Guano No. 966B	3.00	40.1	39.7	43.7	40.6		41.0±1.1	27	18	57.9	44.2	52.0	45.9		50.0±2.1	23
Guano No. 975	4.00	35.4	18.7	26.0	35.7		29.0±2.8	13	9	14.7	13.7	24.9	19.0		18.1±1.5	5
Guano No. 977	1.20	53.8	47.8	47.0	55.5		51.0±1.4	88	58	55.4	56.7	61.1	57.0		57.6± .8	69

TABLE XIV.—*Effect of remaining in the soil on the availability of the phosphoric acid of guanos.*

Source of phosphoric acid (P_2O_5).	Kind of soil.	Efficiency of phosphoric acid in guanos compared with that of acid phosphate=100.			Gain (+) or loss (−) in efficiency caused by remaining six weeks in soil.
		Both applied six weeks before planting.	Both applied just before planting.	Guanos applied six weeks before, acid phosphate just before planting.	
Guano No. 797A	Sand	30	24	15	− 9
Do	Clay	57	50	37	−13
Do	Clay, limed	39	30	27	− 3
Guano No. 811A	Sand	15	9	8	− 1
Guano No. 842A	....do	37	22	19	− 3
Guano No. 851	Clay	50+	48	50+	+ 2+
Do	Clay, limed	25	15	17	+ 2
Guano No. 860	Sand	36	19	20	+ 1
Guano No. 889	....do	17	11	11	0
Guano No. 923	....do	7	6	6	0
Guano No. 966B	Clay	27	29	25	− 4
Do	Clay, limed	27	23	18	− 5
Guano No. 975	Clay	50+	50+	50+	0
Do	Clay, limed	13	5	9	+ 4
Guano No. 977	Clay	111	....	80	....
Do	Clay, limed	88	69	58	−11
Bone meal	Sand	40	23	21	− 2
Do	Clay	100+	57	84	+27
Do	Clay, limed	38	22	25	+ 3
Floats	Sand	4	3	2	− 1
Do	Clay	40+	29	40+	+11+
Do	Clay, limed	3	1	3	+ 2

The third column in Table XIV gives the efficiencies of the guanos relative to acid phosphate when all materials were added to the soil six weeks before planting, and the fourth column gives the efficiencies when materials were added immediately before planting. It will be noted that *relative to acid phosphate* nearly all guanos were more effective when applied six weeks before planting than they were when applied immediately before planting. This does not show that the absolute availability of the guanos and other phosphates was increased by remaining in the soil, as the greater efficiency relative to acid phosphate may be merely due to a depression in the availability of acid phosphate produced by remaining in the soil. The fifth column elucidates this.

In the fifth column, efficiencies of guanos, bone meal, and floats, added to the soil six weeks before planting, are compared with those of acid phosphate applied immediately to the crop. The values in the fifth column should be greater than those in the fourth, if the availability of the other phosphates has really been increased (rather than that of acid phosphate depressed) by remaining in the soil. As a matter of fact, most of the materials lost in efficiency by remaining in the soil, although they lost less than acid phosphate. In the sixth column is shown the amount the materials actually gained or lost in efficiency by remaining in the soil.

The results in Table XIV show that when guanos remain six weeks in the soil, the availability of the phosphoric acid is slightly depressed, in others slightly increased, and in most guanos very little affected. The availability of bone meal and floats was quite markedly increased by remaining in the clay and very little depressed in the sand.

In the red clay the favorable or unfavorable effect of remaining in the soil was more marked than in the sand.

Liming the red clay tended to diminish the increase or decrease in availability produced by remaining in the soil.

Efficiency of the phosphoric acid as affected by liming.—It has been shown by Prianishnikov [1] and Wheeler [2] that the efficiencies of many phosphates are notably affected by liming, while others are only slightly affected. Obviously the degree to which availabilities are affected depends somewhat on the nature of the soil and the length of time the phosphates remain in the soil before they are assimilated by the crop.

To gain some idea of how bat guanos are affected by liming, the efficiencies of bone meal, floats, slag, and 11 guanos were compared with those of acid phosphate in limed and unlimed red clay and river sand. Detailed results of the tests are given in Tables XIII and XV, a summary of the results in Table XVI.

For the test in Table XV, millet plants were grown 30 to the pot in river sand No. 213 (41 pounds dry soil per pot with a water content of 18 per cent). The crop was produced from August 17 to September 29, 1916, with a basic fertilizer consisting of 8.4 grams sodium nitrate, 6 grams ammonium sulphate, and 8 grams potassium sulphate per pot given in two applications.

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[1] Prianishnikov, D. Über den Einfluss von kohlensaurem Kalk auf die Wirkung von verschiedenen Phosphaten. Landw. Vers. Stat., 75 (1911), No. 5-6, pp. 357-376.

[2] Wheeler, H. J. After-effects of certain phospates on limed and unlimed land. Jour. Indus. and Engin. Chem., 2 (1910), No. 4, pp. 133-135.

TABLE XV.—*Effect of lime on availability of phosphoric acid in guanos.*

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Oven-dry yield of individual pots.						Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate in the same soil.	Efficiency of phosphates and guanos in limed soil compared with that of acid phosphate in unlimed soil.
NO LIME.										
	Gm.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*		
No phosphate	....	38.3	42.1	42.1	41.9	37.3	41.5	40.4±0.6	....	....
Acid phosphate	0.40	58.2	52.2	55.8	54.7	59.5	52.5	55.5± .8	....	....
Do	.80	70.0	69.9	64.3	71.6	73.3	66.3	69.2± .9	....	....
Do	1.40	80.6	70.5	88.1	75.5	66.2	73.4	75.7±2.1	....	....
Do	2.10	90.0	87.0	89.9	85.6	90.1	88.3	88.5± .5	....	....
Bone meal	3.00	73.9	66.7	74.7	68.6	65.7	73.3	70.5±1.1	31	....
Floats	8.00	50.1	53.3	48.9	54.9	62.7	59.1	54.8±1.4	5	....
Basic slag	1.00	59.6	60.4	63.8	56.5	65.0	66.5	62.0±1.0	59	....
Guano No. 811A	6.00	54.7	64.3	62.8	60.2	42.8	62.9	58.0±2.3	8	....
Guano No. 842	3.00	63.2	68.4	65.4	61.9	58.9	64.0	63.6± .9	21	....
Guano No. 851	4.50	68.2	70.1	71.2	61.9	71.1	66.8	68.2±1.0	17	....
Guano No. 860	3.00	76.6	72.4	65.0	64.1	61.3	72.3	68.6±1.6	26	....
Guano No. 889	5.00	66.1	68.0	62.5	60.6	59.7	69.8	64.5±1.1	13	....
Guano No. 923	7.00	52.6	46.9	50.8	51.4	49.4	......	50.2± .7	4	....
Guano No. 957	2.00	59.6	69.1	60.6	62.3	54.9	......	61.3±1.5	29	....
Guano No. 966B	3.00	50.5	49.0	50.1	49.6	50.8	......	50.0± .2	8	....
Guano No. 977	1.00	72.3	75.2	64.9	74.3	66.1	......	70.6±1.3	93	....
AIR-SLAKED LIME, 10 GRAMS PER POT.										
No phosphate	....	36.3	34.7	39.3	42.9	22.3	43.8	36.6±2.1	....	....
Acid phosphate	0.40	49.5	53.2	51.2	46.9	46.9	49.7	49.6± .7	....	....
Do	.80	55.8	62.9	48.3	59.7	62.5	62.3	58.6±1.6	....	....
Do	1.40	74.6	73.2	69.2	70.0	81.7	84.1	75.5±1.7	....	....
Do	2.10	77.2	79.4	81.2	73.9	76.8	80.9	78.2± .8	....	....
Bone meal	3.00	38.0	43.8	40.6	45.5	55.4	46.3	44.9±1.6	9	4
Floats	8.00	39.1	38.8	33.4	37.8	36.8	45.7	38.6±1.1	1	0
Basic slag	1.00	50.8	47.7	50.9	48.6	56.8	57.7	52.1±1.1	51	31
Guano No. 811A	6.00	61.2	57.4	60.2	65.9	61.7	59.3	61.0± .8	15	9
Guano No. 842	3.00	45.1	33.4	36.2	42.3	43.6	44.3	40.8±1.3	4	0
Guano No. 851	4.50	53.5	55.7	49.6	48.6	57.7	57.2	53.7±1.1	13	8
Guano No. 860	3.00	36.9	43.3	40.2	40.6	42.7	46.2	41.7± .9	5	0
Guano No. 889	5.00	41.6	46.6	39.4	42.0	47.8	47.6	44.2±1.0	5	2
Guano No. 923	7.00	50.1	50.1	47.3	47.7	51.6	45.8	48.8± .6	6	3
Guano No. 957	2.00	57.4	62.7	64.7	59.4	63.7	66.7	62.4± .9	47	30
Guano No. 966B	3.00	43.9	49.1	54.1	51.0	53.4	37.5	48.2±1.7	12	7
Guano No. 977	1.00	54.8	57.3	51.1	54.0	57.2	54.6	54.8± .6	63	38

TABLE XVI.—*Effect of limed and unlimed soil on the availability of the phosphoric acid of guanos.*

Source of phosphoric acid (P_2O_5).	Kind of soil.	Efficiency of phosphoric acid in guanos compared with that of acid phosphate=100.			Gain (+) or loss (−) in efficiency caused by liming.
		Both applied to unlimed soil.	Both applied to limed soil.	Guanos applied to limed soil, acid phosphate to unlimed soil.	
Guano No. 797A	Clay	50	30	40	−10
Guano No. 811A	Sand	8	15	9	+ 1
Guano No. 842	do	21	4	0	−21
Guano No. 851	do	17	13	8	− 9
Do	Clay	48	15	15	−33
Guano No. 860	Sand	26	5	0	−26
Guano No. 889	do	13	5	2	−11
Guano No. 923	do	4	6	3	− 1
Guano No. 957	do	29	47	30	+ 1
Guano No. 966B	do	8	12	7	− 1
Do	Clay	29	23	27	− 2
Guano No. 975	do	50+	5	2	−48+
Guano No. 977	Sand	93	63	38	−55
Do	Clay	....	69	90	....
Bone meal	Sand	31	9	4	−27
Do	Clay	57	22	13	−44
Floats	Sand	5	1	0	− 5
Do	Clay	29	1	0	−29
Slag	Sand	59	51	31	−28

The third column of Table XVI shows the efficiency of the different materials relative to acid phosphate when both acid phosphate and the materials were added to the unlimed soil; the fourth column gives efficiencies relative to acid phosphate in the limed soil. A comparison of results in the third and fourth columns shows whether the efficiencies of bone meal, floats, slag, and guanos have been decreased more or less than the efficiency of acid phosphate by liming. As the availability of acid phosphate was reduced in the limed soil, a comparison of values in the third and fourth columns does not give the absolute gain or loss in availability produced by liming, but the loss relative to that suffered by acid phosphate.

In the fifth column are calculated the efficiencies of guanos, etc., in the limed soil relative to acid phosphate in the unlimed soil. A comparison of values in the third and fifth columns, therefore, gives the absolute gain or loss produced by liming in efficiency of the materials. This absolute gain or loss is expressed in the sixth column.

It is apparent (by comparing values in the third and fourth columns) that the efficiencies of guanos Nos. 811A, 923, 957, and 966B were depressed less by liming than the efficiency of acid phosphate, while the efficiencies of bone meal, floats, and all other guanos were depressed to a much greater extent than that of acid phosphate. The efficiencies of slag and acid phosphate were affected about equally.

In regard to absolute gain or loss in availability (comparison of values in third and fifth columns), it can be seen that guanos Nos. 811A, 923, 957, and 966B were practically unaffected by liming; while all other guanos, together with bone meal, floats, and slag, suffered moderate to extreme losses in availability.

Liming decreased the efficiency of the phosphates more in the red clay than in the sand. This was due to the fact that certain materials have an enhanced availability in the acid clay (see Table XI). The degree to which liming affects the efficiency of phosphates thus depends largely on the nature of the soil as well as on the character of the phosphate.

The influence of lime on the efficiencies of phosphates applied to the soil six weeks before planting was pointed out on page 38.

Effect of quantity of guano used on efficiency of the phosphoric acid.—In the preceding tests some of the guanos had a very low availability, only 2 to 10 per cent of that of acid phosphate. It was expected that the availability of such materials would be independent of the quantity used in the experiment; nevertheless this point was tested, as it is of considerable practical importance. If the availability of the materials is independent of the quantity used, then a maximum effect can be secured if a sufficient quantity is used.

Table VIII affords detailed results of tests of several different quantities of the same guano, summarized results being given in Table XVII.

TABLE XVII.—*Effect of quantity of guano used on immediate availability of phosphoric acid in guanos.*

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Efficiency of phosphoric acid compared with that of acid phosphate=100.	Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Efficiency of phosphoric acid compared with that of acid phosphate=100.
	Grams.			*Grams.*	
Guano No. 508	3.6	2	Guano No. 734	1.2	39
	14.4	1		1.8	36
Guano No. 509	3.6	2		2.7	39
	7.2	3		4.05	45
	14.4	3	Floats	6.0	7
	28.8	2		18.0	4

Where availabilities varied with the quantity of guano applied, the differences were within the limits of experimental error. The results as a whole show that the availability of the guanos is maintained when large amounts are used and, therefore, if applied in sufficient quantity, they will produce the same increased yield as commercial phosphates.

Efficiency of the phosphoric acid as affected by the stage of growth of the crop.—An attempt was made to determine whether the guanos were equally efficient phosphatic fertilizers at all stages of the plant's growth. It might be thought that the more unavailable phosphates would be more efficient during the later stages of plant growth, when the root system is more developed, than during early growth.

The efficiencies of bone meal and seven guanos were tested relative to acid phosphate with millet grown 31, 41, and 51 days, or with corn grown 39 and 55 days. River sand No. 213 with a water content of 18 per cent was used, 46 pounds dry soil per pot for the corn, 47 for the millet crops. The corn was grown from February 2 to March 29, 1915, the millet from July 4 to August 24, 1915. At 31 days the heads of millet were just appearing, at 41 days seeds were forming but were not fully ripe, and at 51 days the seeds were ripe and the plant commencing to dry. The corn commenced to show pronounced joints at 39 days (after transplanting seedlings to pots) and at 55 days tassels were out on many plants. In order that plants grown 55 days might not be restricted in growth by the size of the pot more than those grown 39 days, four seedlings to a pot were planted in the 39-day series and 2 seedlings to a pot in the 55-day series, while 29 millet plants were grown per pot for all three tests. Results of the tests are given in Table XVIII.

TABLE XVIII.—*Effect of period of growth of crop on the immediate availability of the phosphoric acid in guanos.*

CORN GROWN 39 DAYS.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Basic fertilizer applied per pot.	Oven-dry yield of individual pots.					Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate=100.
	Gm.		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	
No phosphate	....	Sodium nitrate, 8.4 gm.; ammonium chlorid, 5.3 gm.; potassium sulphate, 8 gm.; in two applications.	11.2	6.3	6.9	8.9	5.9	7.8±0.7	....
Acid phosphate	0.30		18.4	16.9	13.4	18.7	9.5	15.4±1.1	....
Do	.60		28.8	32.5	37.2	33.9	21.7	30.8±1.8	....
Do	.90		56.2	34.1	49.3	50.8	45.6	47.2±2.5	....
Do	1.35		69.2	68.9	61.1	59.8	61.2	64.0±1.4	....
Do	2.03		86.1	86.6	84.3	87.4	89.6	86.8± .6	....
Guano No. 500	2.40		42.6	37.1	44.4	33.0	30.8	37.6±1.8	30
Guano No. 503	1.40		63.1	61.1	56.1	64.1	46.3	58.1±2.2	86
Guano No. 504	10.00		9.9	6.7	9.3	8.2	7.3	8.3± .4	0
Guano No. 507	3.00		50.2	47.0	41.7	50.2	45.2	46.9±1.1	30

TABLE XVIII.—*Effect of period of growth of crop on the immediate availability of the phosphoric acid in guanos*—Continued.

CORN GROWN 55 DAYS.

Source of phosphoric acid (P_2O_5).	Phosphoric acid applied per pot.	Basic fertilizer applied per pot.	Oven-dry yield of individual pots.					Average oven-dry yield and probable error.	Efficiency of phosphoric acid as compared with that of acid phosphate=100.
	Gm.		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	
No phosphate	....	Sodium nitrate, 8.4 gm.; ammonium chlorid, 5.3 gm.; potassium sulphate, 8 gm.; in two applications.	25.4	33.4	20.8	20.2	24.6	25.3±1.2	....
			34.4	18.6	29.7	26.0	19.8		
Acid phosphate	0.30		57.1	37.4	31.8	57.0	49.0	46.0±2.0	....
			43.5	47.7	60.2	46.6	29.3		
Do	.60		100.1	79.7	87.6	84.8	96.0	81.9±2.6	....
			84.7	83.0	69.5	68.2	65.4		
Do	.90		104.2	117.9	100.3	108.4	102.3	101.0±2.2	....
			87.7	86.4	99.0	112.0	92.2		
Do	1.35		118.6	146.6	144.0	103.5	119.3	124.6±2.9	....
			121.3	127.6	107.7	130.7	126.4		
Do	2.03		144.0	147.4	167.1	140.6	171.9	153.8±2.5	....
			151.6	142.6	145.0	160.4	167.6		
Guano No. 500	2.40		68.0	82.4	100.4	100.0	114.1	89.2±3.6	30
			68.9	108.0	95.7	85.6	69.2		
Guano No. 503	1.40		94.0	82.8	125.9	122.5	117.0	108.8±2.9	74
			107.6	122.6	105.0	110.4	100.5		
Guano No. 504	10.00		25.0	35.2	31.5	38.5	27.8	26.7±1.6	0
			30.7	23.1	21.8	14.4	18.5		
Guano No. 507	3.00		107.7	86.5	105.6	89.4	95.9	96.9±2.1	28
			94.2	107.9	102.2	91.0	78.4		

MILLET GROWN 13 DAYS.

No phosphate	....	Sodium nitrate, 8.4 gm.; ammonium sulphate, 6 gm.; potassium sulphate, 8 gm.; in two applications.	7.8	10.6	10.0	10.3	9.0	9.5±0.3	....
Acid phosphate	0.30		19.6	20.0	16.6	19.7	18.2	18.8± .4	....
Do	.60		24.5	26.7	26.3	27.6	23.5	25.7± .5	....
Do	.90		31.2	27.3	30.5	28.8	26.9	28.9± .6	....
Do	1.35		30.4	33.3	32.8	32.8	29.5	31.8± .5	....
Do	2.03		33.6	36.0	33.3	32.8	27.1	32.6±1.0	....
Guano No. 499A	3.20		20.1	23.8	24.6	26.4	22.4	23.5± .7	16
Guano No. 503A	1.40		27.2	29.2	29.8	31.6	28.7	29.3± .5	70
Guano No. 505A	8.00		18.4	17.5	15.6	18.0	15.0	16.9± .5	3
Bone meal	3.00		30.0	29.0	28.4	25.3	29.8	28.5± .6	29
Guano No. 818	3.20		28.4	30.3	28.1	29.6	24.4	28.2± .7	26

MILLET GROWN 41 DAYS.

No phosphate	....	Sodium nitrate, 8.4 gm.; ammonium sulphate, 6 gm.; potassium sulphate, 8 gm.; in two applications.	22.3	19.7	21.0	18.4	22.2	20.7±0.5	....
Acid phosphate	.30		32.9	33.1	35.7	34.9	34.3	34.2± .4	....
Do	.60		41.1	43.0	44.0	38.9	45.8	42.6± .8	....
Do	.90		47.6	51.9	50.3	56.0	47.0	50.6±1.1	....
Do	1.35		57.1	61.1	54.0	51.1	60.7	56.8±1.3	....
Do	2.03		58.1	62.7	58.4	61.3	52.4	58.6±1.1	....
Guano No. 499A	3.20		37.0	40.0	41.7	47.4	32.3	37.7±1.1	13
Guano No. 503A	1.40		43.0	49.4	41.9	53.4	46.7	46.9±1.4	54
Guano No. 505A	8.00		29.3	31.4	28.8	34.4	......	31.0± .8	3
Bone meal	3.00		52.7	53.1	45.2	53.9	48.6	50.7±1.1	31
Guano No. 818	3.20		49.7	46.8	48.9	43.7	48.4	47.5± .7	25

MILLET GROWN 51 DAYS.

No phosphate	....	Sodium nitrate, 8.4 gm.; ammonium sulphate, 6 gm.; potassium sulphate, 8 gm.; in two applications.	44.2	34.9	44.6	40.2	42.0	41.2±1.1	....
Acid phosphate	.30		60.7	49.4	55.9	54.1	46.1	53.2±1.7	....
Do	.60		63.6	63.0	57.5	62.7	63.1	62.0± .8	....
Do	.90		63.2	63.2	68.9	68.1	61.3	64.9±1.0	....
Do	1.35		73.3	65.9	69.3	77.0	79.1	72.9±1.6	....
Do	2.03		88.0	78.8	90.2	92.5	79.7	85.8±1.9	....
Guano No. 499A	3.20		58.0	54.8	58.0	57.6	60.0	57.7± .5	14
Guano No. 503A	1.40		65.6	65.2	66.9	66.0	69.4	66.6± .5	71
Guano No. 505A	8.00		48.2	44.7	48.7	51.9	50.8	48.9± .9	3
Bone meal	3.00		69.1	69.0	73.7	77.5	75.0	72.9±1.1	45
Guano No. 818	3.20		67.1	65.2	60.4	72.0	69.7	66.9±1.3	32

It will be noted that in most cases the agreement between efficiencies determined at various stages of growth was remarkably close. The slight differences that occurred were within the limits of experimental error in all cases except that of bone meal. The greater efficiency of bone meal at the 51-day than at the 31-day stage of the millet crop is probably not due to the fact that bone meal is more available to millet during the later stages of growth, but rather to the fact that the availability of bone meal is not decreased by its remaining in the soil while that of acid phosphate is decreased [1] (see p. 54). The difference in efficiency of bone meal at different periods in the growth of millet is, therefore, due to the action of the soil rather than to that of the crop.

So far as assimilation by the crop is concerned, the guanos seem to be as efficient during the early growth of the plant as during the later growth. Some guanos, during the latter growth of long time crops, may show an increased availability relative to acid phosphate, due to a smaller loss of availability in the guanos on remaining in the soil.

Citrate solubility as a measure of the available phosphoric acid in bat guanos.—Chemical analyses and vegetation tests conducted with 92 different samples of guano afford data for judging the reliability of the citrate method for determining available phosphoric acid in bat guanos and leached bird guanos. In Table XIX is shown the percentage of total phosphoric acid in the guano available by the citrate method and also the immediate efficiency of the total phosphoric acid relative to that of acid phosphate as determined by a vegetation test in a sandy soil. As the phosphoric acid of the acid phosphate was all available,[2] the figures for efficiencies in the vegetation tests also show the percentage of the total phosphoric acid in the guanos which was available.

In Table XIX, the figures for efficiencies by vegetation tests are in many cases averages of the values obtained in several different tests with the same guano. They all represent tests, however, of the immediate efficiency of the phosphoric acid in sandy soil with corn or millet. The results in Table XIX were compiled from portions of Tables IV, VIII, X, XII, and XVIII.

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[1] It should be borne in mind that efficiencies are expressed relative to that of acid phosphate.

[2] Acid phosphate was used in the tests on the basis of the content of available phosphoric acid, not total phosphoric acid.

TABLE XIX.—*Citrate solubility compared with vegetation tests as a measure of the availability of the phosphoric acid in guanos.*

Source of phosphoric acid (P_2O_5).	Citrate-soluble portion of total phosphoric acid in guanos.	Efficiency of phosphoric acid compared with that of acid phosphate =100 by vegetation tests.	Source of phosphoric acid (P_2O_5).	Citrate-soluble portion of total phosphoric acid in guanos.	Efficiency of phosphoric acid compared with that of acid phosphate =100 by vegetation tests.
	Per cent.			*Per cent.*	
Guano No. 263	38	29	Guano No. 816	23	18
Guano No. 263A	48	38	Guano No. 818	23	26
Guano No. 321	22	27	Guano No. 819	80	66
Guano No. 374	23	28	Guano No. 824	3	2
Guano No. 375	21	22	Guano No. 841	27	14
Guano No. 376	56	42	Guano No. 842	21	18
Guano No. 415	5	24	Guano No. 846	11	10
Guano No. 447	40	26	Guano No. 851	28	16
Guano No. 458	38	40	Guano No. 852	89	60
Guano No. 460	43	14	Guano No. 853	13	27+
Guano No. 472	93	94	Guano No. 860	15	23
Guano No. 472A	93	101	Guano No. 881	80	65
Guano No. 497	18	16	Guano No. 889	34	12
Guano No. 498	8	26	Guano No. 912	10	1
Guano No. 499	5	25	Guano No. 916	10	1
Guano No. 499A	9	16	Guano No. 917	28	3
Guano No. 500	16	32	Guano No. 923	20	.5
Guano No. 500A	9	26	Guano No. 928	31	14
Guano No. 501	5	17	Guano No. 931	33	31
Guano No. 502	16	9	Guano No. 932	24	19
Guano No. 503	81	70	Guano No. 936	31	36
Guano No. 503A	68	65	Guano No. 939	26	20
Guano No. 504	....	....	Guano No. 943	12	10
Guano No. 505	....	4	Guano No. 945	46	51
Guano No. 505A	6	3	Guano No. 947	15	10
Guano No. 506	30	8	Guano No. 955	5	2
Guano No. 507	27	29	Guano No. 957	47	34
Guano No. 508	13	2	Guano No. 959	63	33
Guano No. 509	....	3	Guano No. 961	88	49
Guano No. 733	56	64	Guano No. 965	74	18
Guano No. 734	44	39	Guano No. 966A	38	20
Guano No. 750	11	9	Guano No. 966B	....	8
Guano No. 751	84	104	Guano No. 970	46	25
Guano No. 780	80	77	Guano No. 971	68	32
Guano No. 784	46	35	Guano No. 975	11	4
Guano No. 785	52	39	Guano No. 977	92	94
Guano No. 790	13	4	Guano No. 978	82	87
Guano No. 793	28	35	Guano No. 980	13	5
Guano No. 796	....	1	Guano No. 981	12	3
Guano No. 797	39	19	Guano No. 982	73	33
Guano No. 797A	50	24	Guano No. 985	72	31
Guano No. 798	18	4	Guano No. 1011	32	11
Guano No. 799	27	31	Guano No. 1013	10	2
Guano No. 806	34	12	Guano No. 1018	9	2
Guano No. 807	15	6	Floats	2	4
Guano No. 810	16	10	Slag [a]	78	68
Guano No. 811	30	15	Bone meal	....	31
Guano No. 811A	30	9			

[a] Solubility in 2 per cent citric acid.

By the citrate test the 92 samples had an average of 33 per cent of the total phosphoric acid available, and by the vegetation test, 26 per cent.[1] Sixty-four of the 92 samples showed excellent to fair agreement between the chemical and vegetation tests of availability. Of the 28 samples showing poor agreement, 6 gave higher results by the vegetation than by the chemical test, and 22 lower results by the vegetation test. Fresh, or only slightly decomposed, bat manures showed a very fair agreement between the two methods for availabilities.

[1] Where one sample was tested several times, the mean value was used in calculating the general average.

It is evident that for most guanos the citrate solubility is a fair test of the availability of the phosphoric acid, but with many guanos the citrate method gives far too high results. In some cases a serious error would be made in relying on the citrate method. This is not surprising in view of the very variable composition of the guanos. By consulting the complete analyses of guanos in Table III it is apparent that the inaccuracy of the citrate method for certain guanos can not be correlated with the content of any constituents, as iron, alumina, lime, volatile matter, silica, or sulphates.

In judging these results it should be considered that the availability or efficiency of a phosphate is not an unalterable property, but is affected by many conditions already mentioned. On the other hand, solubility of a phosphate in neutral ammonium citrate is a fixed property if the method is rigidly followed. Consequently the citrate solubility can not be a true measure of the efficiency of any phosphate under all conditions. In a comparison of the citrate and vegetation methods for availability, it is, therefore, essential to qualify the conditions of the vegetation tests. Under certain vegetation conditions the availability of the phosphate should be the same as the solubility in ammonium citrate if the chemical method is applicable to the material.

It is reasonable to hold that the citrate method, if it is applicable to a given material, should show the amount of phosphoric acid immediately available to a crop under conditions where phosphatic efficiency is not particularly enhanced or depressed. It is believed that in the tests of immediate availability in river sand there were no special conditions enhancing or depressing the efficiency of the phosphates and that the tests therefore fairly show the applicability of the citrate method to guanos. The fact that in these tests citrate-solubility was a fairly to exceedingly accurate measure of availability with 72 per cent of the samples, but a very inaccurate measure with 28 per cent of the samples, confirms this idea. The agreement of some samples and the nonagreement of others show that the citrate method is not applicable to all kinds of guanos.

Had the vegetation tests all been conducted in the acid clay soil, doubtless nearly all guanos would have shown a greater vegetation than chemical availability. Such a soil, however, would not be a fair medium for determining the applicability of the citrate method.

Summary of results on efficiency of the phosphoric acid in guanos.—Vegetation tests showed that the immediate efficiency of the phosphoric acid in bat and bird guanos varied between 0 and 108, compared with 100 for the efficiency of phosphoric acid in acid phosphate. Samples of fresh bat manure had an average efficiency of 84, showing that they are almost as available as acid phosphate. About half the samples examined had an efficiency of 20 or better, practically

that of bone meal under the same conditions. Nearly all guanos had a higher immediate efficiency than ground rock phosphate, although in a few instances this was lower.

The guanos were equally efficient for corn and millet, and there was no evidence of their being any more efficient for rice.

Four guanos gave the same efficiency (relative to acid phosphate) in a clay soil as in a sand, while eight samples were from 30 to 1,100 per cent more effective in the clay than in the sand. Bone meal and floats also showed increased efficiency in the clay.

Remaining in the soil six weeks before planting the crop slightly increased the efficiency of some guanos, slightly depressed that of others, and markedly depressed the efficiency of acid phosphate. Bone meal and floats lost very slightly in efficiency by remaining in the sand but increased markedly by remaining in the clay. Liming tended to counteract the effect of the soil on availability.

Liming the soil had a practically negative effect on the efficiencies of four guanos, but markedly depressed the availability of acid phosphate. Relative to acid phosphate these four guanos therefore showed increased efficiencies in the limed soil. Seven other guanos suffered a marked to an extreme loss of availability in the limed soil. Bone meal and floats also lost more in availability than acid phosphate in the limed soil, while slag and acid phosphate were affected about equally. Liming the red clay depressed availabilities more than liming the sandy soil.

It was found that the quantity of guano used did not affect the availability of its phosphoric acid. Consequently even guanos of low efficiency will produce maximum yields if they are used in sufficient quantities.

The guanos seemed to be equally efficient at all stages of crop growth so far as assimilation by the plant was concerned. However, most guanos would show a greater availability relative to acid phosphate with a long-time crop than with a quick crop, as most guanos were little affected by remaining in the soil while the availability of acid phosphate was decreased. This is an important consideration under Porto Rican conditions, as cane, citrus fruits, and pineapples are long-time crops.

It was shown that solubility of the phosphoric acid in neutral ammonium citrate was a fair measure of the available phosphoric acid in about 70 per cent of the guanos tested, but an inaccurate method for some samples.

EXPERIMENTS ON EFFICIENCY OF THE NITROGEN IN GUANOS.

Plan of experiments and materials used.—In testing the efficiency of nitrogen in guanos the same plan was used as in the work on phosphoric acid. Work on nitrogen was on a less extensive scale than

that on phosphoric acid, as only 91 of the 247 samples contained 1 per cent or more of total nitrogen. Moreover, in 22 of the 91 samples 50 per cent or more of the total nitrogen was present as ammonia and nitrate, the availabilities of which are known. The object of the following tests was to determine the immediate efficiency of that part of the nitrogen which was not present in a form of known availability. Therefore, as a rule, only samples were tested which had less than 50 per cent of the total nitrogen in the form of ammonia or nitrate.

In four experiments dried blood (containing 14.33 per cent nitrogen) was used as the standard for comparison, and in three experiments sodium nitrate was the standard. It seemed advisable to calculate all the results with sodium nitrate as a basis. In order to do this, a value of 71 was assumed for the efficiencies of blood relative to sodium nitrate in the last two tests. The value of 71 was assumed as being probable from the values actually determined in the other tests. The values for the guanos used in these two tests are consequently subject to doubt within narrow limits.

Corn and millet were the crops grown. The river sand was used in two tests, the red clay in one test, and a mixture of nine parts red clay subsoil and one part sea sand (containing 19.4 per cent carbonate of lime) in three tests. To promote nitrification, slaked lime was incorporated in all soils except the subsoil mixture.

In the three largest tests efficiencies were calculated from the quantity of nitrogen in the crop rather than from the mere weights of the crop. Efficiencies calculated from the analyses of the crop were in most cases practically the same as efficiencies calculated from the green weights. It was thought necessary to analyze the plants, as those receiving blood and some other materials were later in developing and much greener than other plants. No such irregularities occurred in the phosphate experiments.

Immediate efficiency of the nitrogen in guanos.—The tests described above and reported in detail in Table XX were conducted to determine the efficiency of the nitrogen in guanos when applied immediately before planting a short-time crop. In this table the efficiencies of the nitrogen in guanos are expressed relative to the efficiency of nitrogen in sodium nitrate taken as 100. As all the nitrogen in sodium nitrate is available (although not recoverable in the crop), the figures for relative efficiency also express the percentage of the total nitrogen available under the conditions of the experiments. By comparing the figures for efficiency with the figures showing the percentage of the total nitrogen present as ammonia and nitrate, it can be seen to what extent the organic nitrogen is available.[1]

[1] For this calculation it is considered safe to assume that ammoniacal nitrogen has the same availability as nitric nitrogen.

TABLE XX.—*Immediate availability of nitrogen in guanos.*

CORN GROWN SEPT. 29 TO NOV. 17, 1916.

Source of nitrogen (N).	Nitrogen applied per pot.	Basic fertilizer applied per pot.	Dry soil. Kind.	Dry soil. Water content.	Dry soil. Amount per pot.	Number of plants per pot.	Oven-dry yield of individual pots.						Average oven-dry yield and probable error.	Nitrogen in crop.	Efficiency of nitrogen as compared with that of sodium nitrate =100.	Nitrogen present as ammonia and nitrate.	Total nitrogen in guano.
	Gm.			*Per ct.*	*Lbs.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*		*Per ct.*	*Per ct.*
No nitrogen		Basic slag, 45 gm., and potassium sulphate, 18 gm., mixed with soil; acid phosphate, 22.5 gm., in two top dressings.	Mixture 9 parts clay soil and 1 part sea sand.	30	60	6	46.0	55.0	48.0	55.0	50.0		51.0±1.2	0.352			
Sodium nitrate	0.30						82.0	93.0	84.0	63.0	75.0		79.0±3.3	.593			
Do	.60						93.0	108.0	81.0	88.0	92.0		92.0±3.0	.819			
Do	1.00						142.0	114.0	100.0	62.0	128.0		109.0±9.1	1.112			
Do	1.50						116.0	132.0	90.0	140.0	130.0		122.0±5.9	1.525			
Dried blood	1.00						110.0	107.0	77.0	94.0	96.0		97.0±3.9	.786	54		14.33
Guano No. 852A	1.00						117.0	104.0	104.0	95.0	106.0		105.0±2.4	.788	55	67	5.06
Guano No. 855A	1.00						70.0	69.0	73.0	73.0	74.0		72.0± .7	.497	18	15	10.54
Guano No. 881A	1.00						99.0	96.0	103.0	82.0	97.0		95.0±2.4	.703	45	63	13.04
Guano No. 1011	1.00						54.0	52.0	50.0	53.0	59.0		54.0±1.0	.378	3	4	1.80
Guano No. 1079	1.00						95.0	91.0	87.0	102.0	87.0		92.0±2.0	.626	34	39	2.00

CORN GROWN OCT. 5 TO NOV. 21, 1916.

Source of nitrogen (N).	Nitrogen applied per pot.	Basic fertilizer applied per pot.	Dry soil. Kind.	Dry soil. Water content.	Dry soil. Amount per pot.	Number of plants per pot.	Oven-dry yield of individual pots.						Average oven-dry yield and probable error.	Nitrogen in crop.	Efficiency of nitrogen as compared with that of sodium nitrate =100.	Nitrogen present as ammonia and nitrate.	Total nitrogen in guano.
No nitrogen		Basic slag, 36 gm., and potassium sulphate, 3 gm., mixed with soil; acid phosphate, 15 gm., in two top dressings.	Mixture 9 parts clay soil and 1 part sea sand.	30	30	4	23.0	28.0	21.0	25.0	23.0	24.0	24.0±0.7	0.173			
Sodium nitrate	0.25						48.0	54.0	41.0	46.0	34.0	51.0	46.0±2.0	.354			
Do	.50						62.0	56.0	53.0	58.0	54.0	64.0	58.0±1.2	.510			
Do	.85						58.0	66.0	70.0	60.0	64.0	71.0	65.0±1.4	.728			
Do	1.35						73.0	62.0	72.0	79.0	73.0	73.0	72.0±1.5	1.094			
Dried blood	.75						61.0	65.0	60.0	58.0	57.0		60.0± .9	.504	65		14.33
Guano No. 777	.75						32.0	30.0	40.0	40.0	35.0		35.0±1.4	.242	13	13	6.63
Guano No. 780A	.75						56.0	60.0	59.0	55.0	34.0		53.0±3.2	.408	44	44	9.65
Guano No. 809	.75						39.0	33.0	31.0	36.0	50.0		38.0±2.2	.274	19	13	4.28
Guano No. 819A	.75						61.0	59.0	61.0	62.0	56.0		60.0± .7	.444	53	45	4.86
Guano No. 828	.75						42.0	40.0	34.0	40.0	42.0		40.0±1.0	.300	23	21	4.15
Guano No. 854	.75						45.0	46.0	43.0	47.0	48.0		46.0± .6	.313	26	27	9.21
Guano No. 885	.75						39.0	46.0	49.0	47.0	48.0		46.0±1.2	.345	.32	31	10.60
Guano No. 911	.75						28.0	28.0	50.0	27.0	24.0		31.0±3.1	.229	11	2	6.15
Guano No. 935	.75						58.0	61.0	24.0	57.0	60.0		52.0±4.7	.400	44	51	3.32

TABLE XX.—*Immediate availability of nitrogen in guanos*—Continued.

MILLET GROWN OCT. 14 TO NOV. 29, 1916.

Source of nitrogen (N).	Nitrogen applied per pot.	Basic fertilizer applied per pot.	Dry soil. Kind.	Dry soil. Water content.	Dry soil. Amount per pot.	Number of plants per pot.	Oven-dry yield of individual pots.						Average oven-dry yield and probable error.	Nitrogen in crop.	Efficiency of nitrogen as compared with that of sodium nitrate = 100.	Nitrogen present as ammonia and nitrate.	Total nitrogen in guano.
	Gm.			*Per ct.*	*Lbs.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*		*Per ct.*	*Per ct.*
No nitrogen	....	Basic slag, 7 gm.; potassium sulphate, 2 gm.; and acid phosphate, 3 gm.; in two applications.	Mixture 9 parts clay soil and 1 part sea sand.	27	11	14	5.9	7.3	6.4	6.7	9.0	6.6	7.0± .4	0.0760	....	....	....
Sodium nitrate	0.10						14.5	12.1	14.3	15.0	15.0	17.3	14.7± .5	.1388	....	....	....
Do	.20						21.5	21.0	20.6	19.0	19.3	22.4	20.6± .4	.2129	....	....	....
Do	.40						27.0	24.6	22.1	22.1	23.7	20.1	23.3± .7	.3951	....	....	....
Do	.80						23.1	21.2	26.8	23.7	21.7	24.3	23.5± .5	.5434	....	....	....
Dried blood	.40						19.6	17.3	15.0	19.3	21.7	22.1	19.2± .7	.3067	76	....	14.33
Guano No. 812	.40						16.7	12.2	13.4	13.9	17.9	16.6	15.1± .6	.1503	29	29	1.72
Guano No. 847	.40						16.1	14.6	16.7	17.3	16.9	15.6	16.2± .1	.1481	28	20	6.29
Guano No. 939	.40						14.1	12.4	14.3	14.2	14.9	15.1	14.2± .1	.1173	16	15	3.08
Guano No. 941	.40						11.2	16.6	16.1	15.7	15.2	15.7	15.1± .5	.1374	25	22	3.01
Guano No. 969	.40						7.7	10.0	7.6	8.5	8.9	6.5	8.2± .3	.0906	6	2	2.37
Guano No. 971	.40						13.1	12.3	11.0	13.7	14.2	13.0	12.9± .3	.1067	13	13	2.01
Guano No. 982	.40						13.1	10.1	9.0	10.4	8.8	9.1	10.1± .4	.0900	6	5	9.44
Guano No. 1032	.40						9.4	7.8	5.9	6.4	8.9	7.2	7.6± .4	.0813	0	2	2.15
Guano No. 1078	.40						15.8	13.3	11.8	13.9	15.0	15.3	14.2± .4	.1119	14	18	2.14

CORN GROWN JAN. 21 TO MAR. 6, 1916.

Source of nitrogen (N).	Nitrogen applied per pot.	Basic fertilizer applied per pot.	Dry soil. Kind.	Dry soil. Water content.	Dry soil. Amount per pot.	Number of plants per pot.	Oven-dry yield of individual pots.						Average oven-dry yield and probable error.	Nitrogen in crop.	Efficiency of nitrogen as compared with that of sodium nitrate = 100.	Nitrogen present as ammonia and nitrate.	Total nitrogen in guano.
No nitrogen	....	Slaked lime, 10 gm.; potassium sulphate, 9.3 gm.; acid phosphate, 21.3 gm.	River sand No. 213.	18	45	4	52.1	56.6	59.6	61.2	62.9	60.1	58.8±1.1	....	....	....	....
Dried blood	0.20						77.5	72.5	70.3	74.1	69.8	82.7	74.5±1.3	....	89	....	14.33
Do	.40						90.3	82.3	91.9	86.7	78.5	92.3	87.0±1.5	....	89	....	14.33
Do	.80						107.9	107.8	111.8	103.1	100.9	104.3	106.0±1.1	....	89	....	14.33
Do	1.20						128.6	112.0	120.5	112.0	124.6	111.1	118.1±2.1	....	89	....	14.33
Sodium nitrate	.70						107.8	107.5	......	105.2	105.3	100.7	105.3± .9	....	100	....	....
Guano No. 982	.70						64.3	64.5	72.0	64.4	66.6	69.2	66.8± .9	....	12	5	9.44
Guano No. 797A	.70						69.9	68.7	74.1	68.9	70.7	69.9	70.4± .5	....	19	14	2.27
Guano No. 503B	.70						72.7	72.9	71.8	74.7	68.9	77.4	73.1± .8	....	23	24	11.73
Guano No. 497A	.70						65.1	68.7	62.7	62.7	64.2	70.4	65.6±1.0	....	11	....	1.73
Guano No. 966B	.70						73.5	66.7	66.6	63.9	64.1	76.4	68.5±1.4	....	16	8	2.35

CORN GROWN FEB. 18 TO APR. 6, 1916.

No nitrogen	....	Slaked lime, 20 gm.; potassium sulphate, 18 gm.; acid phosphate, 44.8 gm.	River sand No. 213.	18	85	6	146.0	140.0	135.0	147.0	145.0	......	143.0±1.0	....	....	....	....
Dried blood	0.40						173.0	170.0	168.0	165.0	166.0	......	168.0±1.0	....	69	....	14.33
Do	.80						182.0	189.0	186.0	184.0	177.0	......	184.0±1.0	....	69	....	14.33
Do	1.20						203.0	188.0	198.0	184.0	191.0	......	193.0±2.0	....	69	....	14.33
Do	1.80						197.0	195.0	216.0	206.0	203.0	......	203.0±2.0	....	69	....	14.33
Sodium nitrate	1.00						179.0	194.0	202.0	201.0	209.0	......	197.0±3.0	....	100	....	....
Guano No. 472A	1.00						152.0	152.0	160.0	171.0	150.0	......	157.0±2.0	....	15	11	10.25
Guano No. 952	1.00						156.0	156.0	159.0	152.0	151.0	......	155.0±1.0	....	12	7	2.34
Guano No. 811B	1.00						150.0	149.0	152.0	160.0	147.0	......	152.0±1.0	....	9	9	3.28
Guano No. 928	1.00						166.0	145.0	161.0	155.0	155.0	......	156.0±2.0	....	14	9	2.75
Guano No. 977	1.00						164.0	171.0	175.0	176.0	163.0	......	170.0±2.0	....	31	36	12.03

CORN GROWN DEC. 1, 1915, TO JAN. 10, 1916.

No nitrogen	....	Slaked lime, 20 gm.; potassium sulphate, 14 gm.; and acid phosphate, 30 gm.	River sand No. 213.	18	90	6	78.3	75.4	76.6	72.2	81.4	......	76.8±1.0	....	....	....	....
Dried blood	0.50						96.4	111.6	98.6	103.6	97.2	......	105.5±2.3	....	a 71	....	14.33
Do	1.00						107.9	118.4	138.4	105.8	105.4	......	115.2±4.2	....	a 71	....	14.33
Do	1.50						102.4	122.9	121.3	116.4	129.9	......	118.6±3.1	....	a 71	....	14.33
Do	2.25						129.0	118.2	125.8	127.5	106.9	......	121.5±2.8	....	a 71	....	14.33
Guano No. 884	1.25						100.3	94.2	101.8	99.9	109.3	......	101.1±1.6	....	28	21	2.47
Guano No. 889A	1.25						87.8	79.6	81.4	79.6	82.7	......	82.2±2.0	....	6	8	1.01
Guano No. 933	1.25						70.1	86.9	83.4	83.1	82.5	......	81.2±1.9	....	5	1	8.92

a Average values obtained from other tests.

TABLE XX.—*Immediate availability of nitrogen in guanos*—Continued.

CORN GROWN DEC. 1, 1915, TO JAN. 10, 1916.

Source of nitrogen (N).	Nitrogen applied per pot.	Basic fertilizer applied per pot.	Dry soil.			Number of plants per pot.	Green yield of individual pots.						Average green yield and probable error.	Nitrogen in crop.	Efficiency of nitrogen as compared with that of sodium nitrate =100.	Nitrogen present as ammonia and nitrate.	Total nitrogen in guano.
			Kind.	Water content.	Amount per pot.												
	Gm.			*Per ct.*	*Lbs.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*		*Per ct.*	*Per ct.*
No nitrogen	....						498.0	417.0	449.0	422.0	462.0	418.0	444.0± 9.0	....	....	....	....
Dried blood	0.35						527.0	550.0	567.0	573.0	706.0	555.0	580.0±18.0	....	a 71	....	14.33
Do	.70						594.0	538.0	632.0	584.0	586.0	543.0	580.0±11.0	....	a 71	....	14.33
Do	1.05	Slaked lime, 20 gm.; potassium sulphate, 9.2 gm.; acid phosphate, 20 gm.	Red clay	35	40	4	381.0	592.0	644.0	597.0	545.0	684.0	574.0±29.0	....	a 71	....	14.33
Guano No. 884	.90						593.0	577.0	590.0	503.0	593.0	552.0	568.0±10.0	....	b 25	21	2.47
Guano No. 889A	.90						480.0	493.0	439.0	471.0	416.0	508.0	468.0± 9.0	....	b 5	8	1.01
Guano No. 933	.90						474.0	438.0	418.0	423.0	408.0	415.0	429.0± 7.0	....	0	1	8.92

a Average of values obtained from other tests.
b Efficiencies are doubtful, as possible 0.35 per cent nitrogen from dried blood is somewhat in excess of crop requirements.

It will be seen that the 39 samples tested gave quite uniform results, since in practically every case the availability of the nitrogen was about equal to the percentage of the total nitrogen present as ammonia plus nitrate. The average percentage of total nitrogen present in the guanos as ammonia and nitrate was 19.6 per cent, while the average availability of the total nitrogen was 20.4 per cent. Evidently in nearly all samples only a very small portion, if any, of the organic nitrogen was available during the 40 to 50 days of the tests. This low availability of the organic nitrogen can not be attributed to the fact that the soils used were poor mediums for the decomposition of organic nitrogen, since dried blood gave an average availability of 71, a very fair value for the duration of the tests. Even the samples of more or less fresh bat manure, Nos. 472, 503, 780, 854, 881, 885, and 977, showed practically none of the organic nitrogen available during the tests.

The fact that only the ammonia and nitrate nitrogen and none of the organic nitrogen was available in 40 to 50 days does not mean that the organic nitrogen in the guanos will not become available later. It is evident, however, that the organic nitrogen is very slowly available. The fact that insect remains, which form the more slowly decomposing part of the organic nitrogen of bat guanos, are known to decompose in the soil shows that the organic nitrogen is eventually available. Also the fact that, in caves where fresh bat manure is being formed, the surface inch of material often contains only 2 or 3 per cent nitrogen, shows that the decomposition of the nitrogenous compounds is fairly rapid under certain conditions.

Experiments were made to determine how much nitrogen in bat guanos was available in 100 and 140 days, as compared with the amount available in 40 to 50 days. Unfortunately, in these tests increases in the crop through nitrogen fertilization were not large enough to yield reliable results. It is significant, however, that in nearly every case the guanos which had remained in the soil the longer time gave slightly greater yields. If possible, this work will be repeated later.

In using bat guanos as fertilizers, it should be considered that part of the nitrogen (that present as ammonia and nitrate) is immediately available and that the remainder probably does not begin to become available for four months or more. Many guanos, however, contain 50 to 90 per cent of their nitrogen in the immediately available form.

VALUATION OF GUANOS.

In Tables III and IV, a money value per dry ton was given for each guano. This value was estimated as follows: The available phosphoric acid was taken as worth 5 cents per pound. Where vegeta-

tion tests were made with the guano, the amount of available phosphoric acid as shown by the vegetation tests was used in calculating the value, rather than the citrate-soluble portion, but where no vegetation test was made, the citrate-soluble phosphoric acid was taken as the amount available. It should be borne in mind that the values given for guanos which were not tested vegetatively are not so accurate as those for the tested guanos because of the inaccuracy of the citrate method for available phosphoric acid in certain guanos.

Five cents per pound was allowed for water-soluble potash present in guano. This value was taken as being about that prevailing before the European war. The present value (1917) is about 40 cents per pound; the future value can not be predicted. The temporary value of the guanos containing 2 or more per cent of potash is thus considerably greater than that given in the tables.

Twenty cents per pound was allowed for that portion of the nitrogen present as ammonia and nitrate. The remainder of the nitrogen is very slowly, although ultimately, available. An allowance of 5 cents per pound was thus made for that nitrogen not immediately available. There were 68 samples containing from 0.5 to 1.93 per cent of total nitrogen which were not tested vegetatively nor for the solubility of the nitrogen in water. Practically all these gave a qualitative test for nitrates. A value of 10 cents per pound was assumed for the nitrogen in such samples. This value may be a little too high for some samples and too low for others, but the average is considered fair.

In assigning a value to the guanos, consideration was thus made of the immediately available phosphoric acid and potash, and of the immediately and slowly available nitrogen. No allowance was made for the phosphoric acid which was not immediately available. Possibly some allowance should have been made for the insoluble phosphoric acid in guanos containing a high percentage, but the value should be low, as only on certain soils will this form of phosphoric acid show even a low availability. The value of such insoluble phosphoric acid in Porto Rico will be better established when those soil areas are known which respond to insoluble phosphates. In regions where finely ground rock phosphate is used as a fertilizer, the insoluble phosphoric acid in guanos should have an equivalent value, as the availability will average about the same. On account of the low value and efficiency of ground rock phosphate and because of freight charges, there has been no market for this material in Porto Rico up to the present time, and this analogy does not establish a value here.

Bearing in mind that the insoluble phosphoric acid would have an efficiency only on certain soils, about 1 cent a pound might be allowed for the monetary value of insoluble phosphoric acid in guanos containing an appreciable amount. Certain guanos like Nos. 796, 807,

925, 1018, and 1037, with 21.37 to 38.57 per cent phosphoric acid, might have a value for making acid phosphate if they were sufficiently low in iron and alumina and if they existed in sufficient quantity to render their marketing practicable.

The values assigned the fertilizing elements were based on usual prices prevailing in the eastern part of the United States. They should be slightly augmented for Porto Rico, since freight charges raise the price of fertilizers in Porto Rico. Transportation to certain interior districts of Porto Rico enhances the cost of standard fertilizers still further in those districts. On the other hand, it should be borne in mind that the valuations given in Tables III and IV are for a dry ton of material. The material as procured from the cave will contain considerable moisture, and the value must be reduced according to the amount of moisture.

In deciding the monetary value of guanos relative to standard fertilizers, it should also be borne in mind that the standard commercial fertilizers are uniform products of known efficiency, while the value of individual guanos is not so well established. The guanos described here which have been subjected to vegetation tests as well as to chemical analyses can also be considered as of known efficiency, but those which have been merely analyzed are of less certainly established value. For instance, it was shown that the citrate method for availability was fairly accurate with 72 per cent of the samples tested but very inaccurate with 28 per cent of the samples, the tendency being for the citrate method to give too high results. The chances are thus about three to one that a chemical analysis will show fairly closely the availability of the phosphoric acid. Because of this element of doubt a guano high in phosphoric acid not thoroughly tested may be worth somewhat less than the valuation given in Tables III and IV.

All the factors mentioned make it difficult to establish an absolute value for the guanos, but it is believed that those given in the tables are fair. It will be noted that values of the different guanos varied between practically nothing and $47.60 per dry ton, the average for the 247 samples tested being $7.14.

GENERAL REMARKS ON BAT GUANOS.

The analyses and tests reported show the great variation in different bat guanos, in respect to their content of the fertilizing elements and the availability of these elements. The reasons for the variations are given in the first part of this report. Bat guanos, excepting fresh bat manure, can not therefore be regarded as a specific fertilizer in the same sense as modern commercial fertilizers, or even the old Peruvian guano.

The fresh bat manure, however, is a fairly definite material in appearance, composition, and availability of its phosphoric acid. It is

a complete fertilizer, high in nitrogen, medium in phosphoric acid, and low in water-soluble potash. The water-soluble potash, of course, is all available, the phosphoric acid is of high availability (little less than that of acid phosphate), and the nitrogen is in part immediately available and in part slowly available. This material is somewhat similar to tankage, differing in containing potash, in having part of its nitrogen more available and part less available than the nitrogen of tankage, and in containing, as a rule, more immediately available phosphoric acid.

The monetary value of fresh bat manure averages about $33 per dry ton. It should be analyzed where practicable, as it is somewhat variable, especially where not freshly gathered.

As fresh bat manure will lose its soluble and valuable constituents if exposed to leaching, it is well to extract this material from the cave periodically. In Texas some gather the fresh bat manure annually. A cave where much fresh manure is being deposited is evidently a valuable permanent asset.

All other guanos, excepting the fresh material, are incomplete fertilizers, lacking either potash, nitrogen, or both. All bat guanos, however, contain phosphoric acid. As a rule the uncontaminated guano increases in phosphate content as the nitrogen content diminishes. Most bat guanos are to be regarded as phosphatic fertilizers containing a small amount of nitrogen, although some are merely phosphatic fertilizers. They ought to be reinforced by the addition of other materials before being used for certain crops on certain soils.

Most bat guanos, but not all, are to be classed with the low-grade fertilizers, either because of a low percentage of the fertilizing elements, or because of a low availability of the nitrogen or phosphoric acid. This does not mean that they are capable of utilization only under certain conditions, although they can be used more advantageously under some conditions than under others. As guanos contain a variety of other substances besides nitrogen, phosphoric acid, or potash, some persons have an idea that they ought to have a peculiar fertilizing value because of their very complexity. This is not true for the most part, although a few of the bat guanos, in common with the old Peruvian guanos, are particularly effective for certain conditions because of having their nitrogen present in different degrees of availability. Most guanos contain more or less gypsum. Little importance should be attributed to this, since gypsum has proved of fertilizing value only in exceptional cases, aside from its use on soils impregnated with alkali salts.[1]

[1] The favorable action of gypsum on a few soils has been attributed to the furnishing of lime or sulphur, the liberation of potash from soil silicates, and the protection afforded by the calcium ion in antagonism between salts.

Whether it will pay to use a given bat guano to supplement other fertilizing materials depends, of course, on the relative cost of the materials at the place where they are to be used. The valuation of the guanos given in Tables III and IV shows their worth relative to standard fertilizers. It is thus possible to calculate the relative cheapness of guanos and other fertilizers at different places by comparing values and costs.

Guanos are what may be termed neutral fertilizers. There is no danger of an accumulative acid or alkaline effect from their continued or excessive use. However, low-grade guanos containing much carbonate of lime should not be applied in large quantities to pineapples on very sandy soils.

Before transporting guanos from the caves the material should, in many cases, be screened to remove stones and large concretions not easily pulverized, as these have little fertilizing value. If the material is to be stored in bags, the bag should be treated with a dilute solution of copper sulphate to prevent decay, as guano not thoroughly dry will rot through a bag in a few days. This is commonly and erroneously attributed to a caustic action of the guano.

From the estimated quantities of guanos given in the appendix and the valuations assigned in this report, it is evident that bat guano will never form an appreciable part of the fertilizer consumed on the island. Most of the deposits are too valuable, however, to be neglected, and even after these deposits have been extracted, fresh material will be formed having an annual value of several thousand dollars. The fresh material should be removed from the cave frequently, as it is fairly uniform in composition and in nearly all caves (on account of leaching) is worth more when fresh than when partially decomposed.

THE USE OF BAT GUANOS.

For the intelligent use of any fertilizing material it is obviously necessary to know its composition and the availability of its fertilizing components. This information concerning most Porto Rican bat guanos is given in the first part of the report. It is also necessary to know the fertilizer requirement of the particular crop on the particular soil, that is, the best fertilizing formula for the conditions. This information is not given here, but the following remarks on the use of the bat guanos apply to any fertilizer formula.

USE OF DATA IN COMPOUNDING A FORMULA.

The following examples will show how the data contained in this report should be used in making a fertilizer mixture of required formula: Suppose a formula of 3 per cent nitrogen, 12 per cent phosphoric acid, and 12 per cent potash is required and that guano No.

793 is to be used in the mixture. One thousand pounds of such a mixture would contain 30 pounds of nitrogen, 120 pounds of phosphoric acid, and 120 pounds of potash. Table IV shows that guano No. 793 contains 24.87 per cent of phosphoric, acid and Table XIX shows that the immediate efficiency of the phosphoric acid is 35. Guano No. 793 thus contains $\frac{24.87 \text{ per cent} \times 35}{100}$ or 8.7 per cent of immediately available phosphoric acid, or 8.7 pounds in 100 pounds of material. To furnish 120 pounds of available phosphoric acid, $\frac{120}{8.7} \times 100 = 1{,}371$ pounds of guano No. 793 is required. As guano No. 793 also contains 0.99 per cent of nitrogen, the 1,371 pounds will afford $\frac{1{,}371 \times 0.99}{100} = 13.6$ pounds of nitrogen. In this guano it is only safe to allow for an availability of 50 per cent of the total nitrogen; therefore, this guano probably furnishes only 6.8 pounds of available nitrogen. To furnish the rest of the nitrogen (30 pounds − 6.8 pounds = 23.2 pounds), about 160 pounds of nitrate of soda would be needed. This guano will contain practically no water-soluble potash; thus about 240 pounds of a high-grade potash salt will be necessary to supply the 120 pounds of potash required by the formula. The mixture now contains 1,371 pounds of guano No. 793, 160 pounds of nitrate of soda, and 240 pounds of high-grade potash salt, a total of 1,771 pounds. The whole mixture of 1,771 pounds is equivalent to 1,000 pounds of the 3: 12: 12 fertilizer.

Suppose guano No. 881 were to be used in this formula instead of No. 793. Table IV shows that No. 881 contains 13.04 per cent of total nitrogen, but $3.6 + 4.6 = 8.2$ per cent of the nitrogen is present as ammonia and nitrate. Table XX shows that the remainder of the total nitrogen has practically no immediate availability. Thus only a quarter of the remaining nitrogen, or $\frac{13.04 - 8.20}{4} = 1.21$ per cent, can be counted on. Guano No. 881 is estimated to have only 9.41 per cent $(8.20 + 1.21)$ of effective nitrogen, which is conservative. To furnish the 30 pounds of nitrogen required by the formula, about 320 pounds of guano No. 881 is needed. In the 320 pounds of guano No. 881, which contains 4.15 per cent of potash (see Table V), there is 13.3 pounds of potash. For the remainder of the potash about 215 pounds of a high-grade potash salt will be needed. As guano No. 881 contains 8.94 per cent total phosphoric acid which Table XIX shows has an efficiency of 65, it contains 5.81 per cent of immediately available phosphoric acid. The 320 pounds of guano thus furnishes 18.6 pounds of available phosphoric acid. For the rest of the phosphoric acid, 101 pounds acid phosphate or a phosphatic guano, as No. 1017,

could be used. As no vegetation test was made with guano No. 1017, the citrate-soluble portion, 18.52 per cent, is taken as the available phosphoric acid. Of this guano 546 pounds is required. The mixture thus contains 320 pounds of guano No. 881, 215 pounds of a high-grade potash salt, and 546 pounds of guano No. 1017, a total of 1,081 pounds. The 1,081 pounds of mixture is equivalent to 1,000 pounds of the 3:12:12 formula.

It will be noted that, in using the guanos to make a formula, the availability of the nitrogen and phosphoric acid in the guanos was considered, as well as the total amount of these elements present. It should be borne in mind that in the analyses given in the first part of this report percentages are all calculated on the dry material. The material as it exists in the cave contains 10 to 60 per cent of moisture, and the air-dried material contains 3 to 15 per cent moisture. For moist material, the percentages must therefore be reduced and the quantities of guano utilized increased.

MATERIALS FOR MIXING WITH GUANOS.

Most guanos can be mixed with any of the commercial fertilizers without loss of availability in the mixture. A few guanos containing carbonate of lime, should not be mixed with sulphate of ammonia or acid phosphate. A test for carbonate should be made by observing whether the guano effervesces with acid before mixing a guano with such materials. If it is desirable to use a guano containing carbonate with sulphate of ammonia, the sulphate of ammonia should be applied to the soil first and later the guano incorporated with the soil. On the other hand, a few guanos contain considerable ammonium salts, and these should not be mixed with basic slag, as the free lime of the slag will liberate the ammonia.

As certain guano deposits have a peculiar place utility in being located in districts where transportation charges make commercial fertilizers particularly expensive, it is important to use them with other waste fertilizing materials, if possible. A combination of tobacco stems and bat guanos would be equivalent to a complete mixed fertilizer, the tobacco stems furnishing potash and some nitrogen, the guano phosphoric acid and some nitrogen. Where more potash in proportion to the other elements is desired than can be obtained by mixing guano and tobacco stems, wood or bagasse ashes can also be applied, although the ashes should not be mixed with some guanos.

Guanos can also be used to supplement stable manure, as stable manure is relatively deficient in phosphoric acid. A phosphatic guano can be advantageously added to the compost heap as it is

being formed.[1] By making the material more compact, this will tend to conserve ammonia.

Low-grade phosphatic guanos can be mixed with coffee hulls and pulp, which contain a small amount of potash. Doubtless the acetic acid produced in the fermented hulls and pulp will aid somewhat in rendering the phosphates more available. Experiments, however, have not been conducted in support of this conclusion. Composting insoluble phosphatic guanos with waste or decaying citrus fruits and pineapples or with refuse from pineapple canneries would doubtless be quite effective in increasing the availability of the phosphoric acid in such materials.

APPLICATION OF GUANOS.

In applying the guanos it should be borne in mind that most of them contain little water-soluble material. Consequently they will be most effective when well and evenly mixed with the soil.

When fresh bat manure or guanos high in nitrogen and organic matter are to be used for young pineapples, the material may be safely applied in the crown, as is done with dried blood. Even though these guanos should contain considerable ammonia and nitrate there will be little danger of injuring the plants, as the bulky nature of the fertilizer prevents dangerous concentration of soluble salts in any place. Only fresh bat manures or guanos composed chiefly of organic matter should be applied in this way, as other guanos, like soil, will tend to smother the plant.

CROPS ON WHICH GUANOS CAN BE USED.

Compounded with other materials, on the basis of their analysis and efficiency, to make the proper formula, guanos can be used for any crop. There are some specific features about the guanos, however, which make them especially good for long-time crops.

In the previous pages it was shown that the phosphoric acid in guanos lost less in availability by remaining in the soil than that in acid phosphate. Consequently when used in mixtures for citrus trees, pineapples, sugar cane, yams, coconuts, and other crops of a long growing season, many guanos will show a greater efficiency relative to acid phosphate than they will for quick crops like lettuce, radishes, etc. This does not mean that guanos are not effective for quick crops. If used on the basis of the immediate efficiencies indicated in the previous pages, they will be equally as effective as the standard fertilizers.

All the guanos contain a considerable portion of their nitrogen in an insoluble and relatively unavailable form. To this part of the

[1] Mixing insoluble phosphates with stable manure has been advocated as tending to increase the availability of the phosphoric acid, but there is some question as to whether any decided increase in availability results from this treatment.

nitrogen, a value only one-fourth that of the ammoniacal and nitrate nitrogen, was given. It is nevertheless probable that practically all this insoluble nitrogen will become available in time. It should therefore be regarded as of considerable value for a long-time crop or at least for the permanent enrichment of the soil.

SOILS ON WHICH GUANOS SHOULD BE USED.

Work is at present under way to determine the relative efficiencies of the standard phosphatic fertilizers on the different soils of Porto Rico. When this work is completed, quantitative data should be available concerning what phosphates are best for the different soils.

From the general knowledge available on the subject and from the availability tests reported here, it appears that bat guanos should be particularly valuable phosphatic fertilizers for acid soils and for non-calcareous clay soils. On neutral sandy soils they should show an efficiency equal to that assigned them in this report, but not an enhanced efficiency. On strongly calcareous soils many guanos, in common with bone meal and rock phosphate, will have their efficiency lowered much more than that of acid phosphate. A few guanos, however, appear particularly good for calcareous soils, their efficiency being less affected by liming than any of the other phosphates. Thus far no analytical method has been found which will tell whether or not the efficiency of a guano will be affected by liming.

SUMMARY.

Deposits of bat guano are especially common in the Tropics and in subtropical regions, and their fertilizing value has never been investigated thoroughly. Generally they are of small size, consisting of a few to several thousand tons, and they usually occur in limestone caves.

The material may be roughly divided into fresh bat manure, decomposed guano, and leached or phosphatic guano, although this classification is not sharp. Only the fresh bat manure is of fairly constant composition, averaging 10.93 per cent nitrogen, 7.29 per cent total phosphoric acid, 5.54 per cent citrate-soluble phosphoric acid, and 2.3 per cent water-soluble potash. The leached phosphatic guano is similar physically and chemically to leached guanos of bird origin.

Attention was called to the manner in which the different kinds of guano were formed and the conditions determining the composition of the material and its variation in the cave.

Twenty-five samples were subjected to a complete mineral analysis. No one constituent showed any regular variation with any other constituent in any sample. The portion of the total phosphoric acid

which was available also failed to correspond to the amount of any other constituent in the guano.

Two hundred and twenty-two samples were analyzed for the fertilizing constituents only, the maximum percentages found in different samples being as follows: Total nitrogen, 13.04 per cent; nitrogen as ammonia, 3.60 per cent; nitrogen as nitrate, 4.60 per cent; total phosphoric acid, 41.58 per cent; water-soluble phosphoric acid, 2.39 per cent; citrate-soluble phosphoric acid, 28.66 per cent; water-soluble potash, 4.18 per cent. Minimum percentages found in different samples were practically zero for each constituent.

A number of samples were tested by vegetation experiments in pots for the immediate efficiency of their phosphoric acid in a neutral sandy soil. Calling the efficiency of the citrate-soluble phosphoric acid in acid phosphate 100, the efficiency of the phosphoric acid in different bat guanos varied between 0 and 108. About half the samples tested had an availability of 20 or more, which compared well with bone meal under the same conditions, and in most the phosphoric acid was more available than in finely ground rock phosphate.

The phosphoric acid of the guanos was equally available for corn and millet.

Most guanos, in common with bone meal and floats, were far more effective in an acid red clay than in a sandy soil. Some guanos, however, were no more effective in the clay than in the sand.

The efficiencies of nearly all guanos *relative to acid phosphate* were much greater when applied six weeks before planting than when applied immediately. This increased efficiency relative to acid phosphate was due to a depression in the availability of the acid phosphate, as the guanos showed practically no absolute gain in efficiency by remaining in either the clay or the sand.

Four of eleven guanos tested were unaffected in efficiency by liming the soil. The remaining guanos, with bone meal, floats, slag, and acid phosphate, suffered a moderate to extreme loss in availability from liming.

As the efficiencies of the guanos appeared unaffected by the quantity used, they should produce maximum yields if applied in sufficient quantity.

The phosphoric acid in guanos was as efficient during the early growth of corn and millet as during the later stages.

In 70 per cent of the 92 samples tested there was fair to excellent agreement between efficiencies of phosphoric acid as determined by solubility in ammonium citrate and by vegetation experiments. With most of the samples where agreement was poor the citrate solubility was far higher than the vegetative efficiency.

Only 91 of the 247 samples analyzed contained 1 per cent or more of total nitrogen. In 22 of the 91 samples 50 per cent or more of the total nitrogen was present as ammonia and nitrate. Vegetation experiments with 35 samples were quite uniform in showing that the nitrogen present in any form other than ammonia or nitrate had practically no immediate availability.

A conservative value assigned the different guanos, on the basis of prices of fertilizing elements prevailing before the summer of 1914, varies between 0 and $47.60 per dry ton, the average value of the 247 samples being $7.14.

General conclusions are drawn concerning bat guanos as fertilizers, utilization of Porto Rican deposits, materials with which guanos should be compounded, mode of application, and crops and soils on which they should be used.

APPENDIX.

THE GUANO-CONTAINING CAVES OF PORTO RICO.

On account of the many extravagant and misleading statements regarding the extent and richness of the guano and phosphate deposits in Porto Rico, the Agricultural Experiment Station undertook a survey of the guano-containing caves of the island. The work was done by Mr. J. H. M. Fallon, who began the survey in 1915 and with some interruptions continued it for more than a year, 110 caves being explored and the amount and character of the deposits being determined. The examination of the caves showed that many of them contain more or less valuable deposits of guano, which should be more largely used in Porto Rican agriculture.

The caves have been classified by Mr. Fallon as follows: Caves or cavities formed by the fracture and dislocation of strata in mountain sides, the caves being entered through horizontal apertures; sink holes or vertical cavities, usually circular in outline and of varying diameter and depth; and subterranean river beds or passageways abraded by the action of sand, gravel, or rocks carried by water. The contents of the caves are of two kinds, bat guano and leached bird guano. In certain regions the black or blackish guanos are known as "murcielaguina," or bat droppings, and all others are called "abono mineral," or mineral fertilizer. A more accurate classification adopted by Mr. Fallon is: (1) Dry, unmodified bat guano, or new guano, (2) modified bat guano, which has lost some of its soluble contents through leaching, and (3) leached bird guano, or old guano, which is still further described as clean or more or less mixed with sand, etc.

Samples were taken from all the caves for analysis and weighed in a box of known capacity, and from the weight per cubic foot the amount of the different kinds of guano was estimated in tons. Analytical data on the various samples of guano are given in the main portion of this bulletin. While many of the caves were found to contain little, if any, guano, the tonnage in others was large. In most instances the marketing of the guanos will be expensive on account of the primitive methods of extracting them and the distance

of the caves from good roads, but the wider use of this material would not only be beneficial in crop production but would furnish soil elements usually supplied from expensive imported fertilizers.

The following lists give the name or owner of each cave visited, its location, and the amount of guano of all kinds it is estimated to contain. The estimates are believed to be conservative and their aggregates do not by any means include all the possible supplies of the island.

Approximate tonnage of guano in Porto Rican caves.

Name of cave or owner and location.	Amount of guano.	Name of cave or owner and location.	Amount of guano.
	Tons.		*Tons.*
La Tuna, La Tuna, Cabo Rojo	333	Toronja, Cabachuelas de Torrecilla, Morovis	170
Los Chorros, Cotui, San Germán	433	Cerro Hueco, Cabachuelas de Torrecilla, Morovis	139
Guaniquilla No. 1, Guaniquilla, Cabo Rojo	48	De los Puercos, Cabachuelas, Morovis	51
Guaniquilla No. 2, Guaniquilla, Cabo Rojo	449	Alta, Cabachuelas, Morovis	35
Boquilla, Tierras Nuevas, Campo Alegre	441	Archilla, Cabachuelas, Morovis	611
Alta Gracia, El Coto, Manatí	10	Escalera, Cabachuelas, Morovis	112
La Laguna, El Coto, Manatí	128	Convento, Hato Viejo Poniente, Ciales	659
Los Santos, El Coto, Manatí	17	Oscura, Sumidero, Aguas Buenas	390
Central Carmen, Rio Abajo, Vega Baja	35	Clara, Sumidero, Aguas Buenas	50
Miranda, Rio Arriba, Vega Baja	221	Del Rio, Sumidero, Aguas Buenas	50
Hacienda Juanita, between Mayaguez and Las Marías	60	Biafara No. 1, Miraflores, Arecibo	201
La Oscura, Rosario, San Germán	48	Bernardo Méndez, Bayaney, Hatillo	405
El Murcielago, Rosario, San Germán	110	Vilella, Yeguadilla, Hatillo	121
El Colorado, Rosario, San Germán	110	Ollo Oscuro, Santiago, Camuy	976
El Convento, El Cedro, Peñuelas	924	Ludovino Suarez, Arenales, Aguadilla	33
Mapancha, El Coto, Peñuelas	483	California, Centro, Moca	100
Pascual, El Cedro, Peñuelas	439	Rafael Suarez, Centro, Moca	50
El Jaguey, north of Guanica Centrale	16	Cuchilla, Cuchilla, Moca	100
El Horno, north of Guanica Centrale	12	El Jobo, Arenales Bajos, Isabela	172
Santa Rita, south of railroad station	127	Murciélago, Galateo Alto, Isabela	67
La Ballena, foot of hills south of Guanica Centrale	217	Juan Eusebio Acevedo, Galateo Alto, Isabela	447
Caja de Muertos No. 1, northeast of lighthouse	91	Juan Bautista Perez, planas, Isabela	133
Caja de Muertos No. 2, northeast of lighthouse	25	Chito Perez, Planas, Isabela	214
La Majina, Límon	11	Pajita, Callejones, Lares	50
Lucero, Cabachuelas, Morovis	676	Los Cruzes, Callejones, Lares	40
Achotillo, Cabachuelas, Morovis	414	Jose Maria Girao, Lares, Lares	30
San Miguel, Cabachuelas, Morovis	224	Jesus Torres, Lares, Lares	100
La Chiquilla, Cabachuelas, Morovis	90	Callo, Villalba Arriba, Juana Diaz	20
Oscura, Cabachuelas, Morovis	3,144	Naranjo, Naranjo, Juana Diaz	110
Capa Prieta, Cabachuelas, Morovis	67	Los Santos, Vega Redonda, Comerío	212
Pablo Clas, Cabachuelas, Morovis	575	La Mora, Vega Redonda, Comerío	285
		Guaraguao, Vega Redonda, Comerío	30
		Total	16,141

In addition the following caves were explored and little or no guano found:

- Three small caves, Rosario, San Germán.
- Ventana, Hacienda La Ventana, Guayanilla.
- El Negro, Duey, Yauco.
- La Pacheca, Naranjo, Yauco.
- Concho Clas, Cabachuelas, Morovis.
- La Gonzalez, Hato Viejo Poniente, Ciales.
- Biafara No. 2, Miraflores, Arecibo.
- Juan Encarnación Cortés, Corrales, Aguadilla.
- Celestino Cortés, Corrales, Aguadilla.
- Ramon Añeses, Corrales, Aguadilla.
- Mercedes Reinan, Corrales, Aguadilla.
- Tomás Torres, Corrales, Aguadilla.
- El Isleño, Corrales, Aguadilla.
- Hondo, Caimital Bajo, Aguadilla.
- Golondrina, Caimital Bajo, Aguadilla.
- Antonio Herrera, Caimital Bajo, Aguadilla.
- Pablo Letri, Caimital Bajo, Aguadilla.
- Sergio Llore, Caimital Bajo, Aguadilla.
- Felipe Llore, Caimital Bajo, Aguadilla.
- Pablo Gonzalez, Camaseyes, Aguadilla.
- Pedro Roldán, Camaseyes, Aguadilla.
- Mamaleona, Terranova, Quebradillas.
- Rafael Marichal, Cacao, Quebradillas.
- Gabriel Piñeiro, Coto, Isabela.
- Domingo Fernandez, Mora, Isabela.
- Barreto, Arenales Bajos, Isabela.
- Caña de la India, Arenales Bajos, Isabela.
- Sin Fin, Arenales Bajos, Isabela.
- Sol, Callejones, Lares.
- Antonio Quily, Callejones, Lares.
- De Agua, Callejones, Lares.
- Seca, Callejones, Lares.
- Gregorio Velez, Callejones, Lares.
- Tayote, Callejones, Lares.
- Jose Alisea, Callejones, Lares.
- Celestino Rivera, Callejones, Lares.
- Cerro de José Cruz, Lares, Lares.
- Clara, Guayabal, Juana Diaz.
- Oscura, Guayabal, Juana Diaz.
- Iglesia, Jaguey, Juana Diaz.
- El Gigante, Vega Redonda, Comerío.
- Cachimbo, Vega Redonda, Comerío.
- Iglesita, Vega Redonda, Comerío.
- Honda, Vega Redonda, Comerío.
- Rafael Domenech, Caimital Bajo, Aguadilla.

Information and detailed data regarding all the above-named caves are in the possession of the experiment station at Mayaguez.

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